SBIR 99-1

National Aeronautics and Space Administration

SBIR:
Small Business Innovation Research

1999 Program Solicitation

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Closing Date: July 14, 1999

Cover: The NASA developed GOES 8 satellite imagery of Hurricane Georges, September 24, 1998. Superimposed is an artistic rendering of the satellite itself. Cover designed by Hal Pierce and Jan Kalshoven at the facilities of the Laboratory for Atmospheres of NASA's Goddard Space Flight Center.

Contents of NASA SBIR 99-1 Program Solicitation

1999 NASA Small Business Innovation Research Program Solicitation

1. Program Description

1.1 Summary

The National Aeronautics and Space Administration (NASA) invites eligible small business concerns (SBCs) to submit Phase-I proposals for its 1999 Small Business Innovation Research (SBIR) Program. The 1999 Solicitation period for Phase-I proposals begins April 24, 1999 and ends July 14, 1999. NASA seeks innovative concepts addressing the program needs and offering commercial application potential as described in the Solicitation subtopics.

Subject to the availability of funds, NASA plans to select about 270 proposals in late October, 1999 for negotiation of Phase-I fixed-price contracts. NASA anticipates that about 40 percent of these Phase-I projects will be selected for Phase-II.

This Solicitation contains program background information, outlines eligibility requirements for participants, describes the three SBIR program phases, and provides information for submitting responsive proposals.

1.2 Program Features

1.2.1 Legislative Basis. This Solicitation is issued pursuant to the authority contained in P.L. 97-219, as amended (Small Business Innovation Development Act of 1982) (15 U.S.C. 638). SBIR policy is provided by the Small Business Administration (SBA) through its Policy Directive dated January 26, 1993.

1.2.2 Program Purposes. The purposes of the SBIR program as established by law are: to stimulate technological innovation in the private sector; to strengthen the role of small business concerns in meeting federal research and development needs; to increase the commercial application of these research results; and to encourage participation of socially and economically disadvantaged persons and women-owned small businesses.

1.2.3 Program Funding. Participating agencies conduct SBIR programs by reserving a small percent of their research and development budgets for funding agreements with SBCs for research or research and development (R/R&D) during the first two phases of the three-phase process. Each agency, at its sole discretion, selects the technical topics and subtopics included in its solicitation. Follow-on Phase-III activities are funded by non-SBIR sources for the pursuit of private sector or Government sales.

1.2.4 Program Management. The NASA Office of Aero-Space Technology provides overall policy direction for the SBIR program. The Program Management Office is hosted at the Goddard Space Flight Center. NASA Field Installations identify R&D needs, evaluate proposals, make recommendations for selections, and manage individual projects. All NASA Strategic Enterprises and Field Installations participate in the program. NASA installations are:

ARC	**Ames Research Center**, Moffett Field, California
DFRC	**Dryden Flight Research Center**, Edwards, California
GRC	**Glenn Research Center** (formerly Lewis Research Center), Cleveland, Ohio
GSFC	**Goddard Space Flight Center**, Greenbelt, Maryland
HQ	**NASA Headquarters**, Washington, DC
JPL	**Jet Propulsion Laboratory**, Pasadena, California
JSC	**Lyndon B. Johnson Space Center**, Houston, Texas
KSC	**John F. Kennedy Space Center**, Kennedy Space Center, Florida
LaRC	**Langley Research Center**, Hampton, Virginia
MSFC	**George C. Marshall Space Flight Center**, Marshall Space Flight Center, Alabama
SSC	**John C. Stennis Space Center**, Stennis Space Center, Mississippi

1.3 Three Phase SBIR Program

1.3.1 Phase-I. The purpose of Phase-I is to determine the scientific and technical merit, feasibility of the proposed innovation and quality of the SBC's performance with a relatively small NASA investment before consideration of further federal support in Phase-II.

To be eligible for Phase-I selection, a proposal must be based on an innovation having high technical or scientific merit that is responsive to a NASA need described by a subtopic in this Solicitation. Proposals involving high risk are encouraged when the anticipated payoff potential is great. Proposals are expected to emphasize near-term applicability to NASA. Selection preference will be given to eligible proposals where the innovations are judged to have significant potential for commercial application. Unsolicited proposals will not be accepted.

Phase-I must concentrate on establishing the scientific or technical merit and feasibility of the proposed innovation and on providing a basis for continued development in Phase-II. Proposals must conform to the format described in Section 3.2 of this Solicitation. Evaluation and selection criteria are described in Section 4.1. NASA is solely responsible for determining the relative merit of proposals, their selection for award, and judging the value of Phase-I results.

SBCs must have the capability to independently conduct the proposed R/R&D. Phase-I projects should not require the use of NASA facilities or equipment (Section 5.14). Contractors will have no more than 6 months to perform Phase-I projects and to submit their final reports and Phase-II proposals.

1.3.2 Phase-II. The objective of Phase-II is to continue development of those innovations shown to be feasible in Phase-I, and which have the highest potential value to NASA and the U.S. economy. The Government is not obligated to fund any specific SBIR Phase-II proposal. **Only Phase-I awardees are eligible to participate in Phase-II.**

Phase-II projects are chosen as a result of competitive evaluations based on selection criteria provided in Section 4.2. Evaluations include consideration of the Phase-I results and place increased emphasis on non-government commercial application potential. Phase-II proposals are more comprehensive than those required for Phase-I and are to be prepared in accordance with instructions provided in the Phase-I contract. See Section 3.3 for required contents of Phase-II proposals.

1.3.3 Phase-III. NASA may award Phase-III contracts for products or services, with non-SBIR funds. Phase-III awards to SBCs to continue work performed under Phase-II contracts are authorized as competitive procedures under the Competition in Contracting Act. The small business is also expected to use non-federal capital to pursue private sector applications of the R/R&D effort.

1.4 Eligibility to Participate in the SBIR Program

1.4.1 Small Business Concern. Only firms qualifying as SBCs as defined in Section 2.5 of this Solicitation are eligible to participate in the SBIR program. Socially and economically disadvantaged and women-owned SBCs are particularly encouraged to propose.

1.4.2 Place of Performance. For both Phase-I and Phase-II, the R/R&D must be performed in the United States (Section 2.7).

1.4.3 Principal Investigator. The Principal Investigator (PI) is considered key to the success of the effort. The following requirements are mandatory:

> **Functions.** The functions of the PI are: planning and directing the SBIR project; leading it technically and making substantial personal contributions during its implementation; serving as the primary contact with NASA on the project; and ensuring that the work proceeds according to contract agreements. Competent management of PI functions is essential to project success. The Phase-I proposal shall describe the nature of the PI's activities and the amount of time that the PI will apply personally on the project. The amount of time the PI proposes to spend on the project must be acceptable to the NASA contracting officer.

Qualifications. The qualifications and capabilities of the proposed PI and the basis for PI selection are to be clearly presented in the proposal. NASA has the sole right to accept or reject a substitute PI based on factors such as education, experience, demonstrated ability and competence, and any other evidence related to the specific assignment.

Co-Principal Investigators. Co-PI's are not acceptable.

Misrepresentation or Substitution. Misrepresentation of PI qualifications and eligibility, or substitution of a PI by the offeror at any time without NASA's advance written approval, will result in rejection of the proposal or termination of the contract.

Primary Employment. The offeror must certify in the proposal that the primary employment of the PI will be with the SBC at the time of award and during the conduct of the project. Primary employment means that the PI will average a minimum of 20 hours per week with the SBC, and that more than half of the PI's total employed time (including all concurrent employers, consulting, and self-employed time) is spent with the SBC. If the PI does not meet these primary employment requirements, the offeror must explain how these requirements will be met if the proposal is selected for contract negotiations that may lead to an award.

Employees of Academic and Non-Profit Organizations. An offeror proposing a PI who is also to be employed concurrently in any capacity by an academic or non-profit organization must include, as part of the proposal, a written release statement. The PI release statement shall approve concurrent primary employment with the SBC as defined above, and agree to less than half-time employment by the organization beginning no later than the time of NASA SIBR contract award and continuing thereafter during contract performance. The organization must specifically release the employee from all duties, responsibilities, and activities required by or implied by employment in that position as much as or more than half-time. Proposals that do not include the required written release statement may be rejected.

1.5 General Information

1.5.1 Electronic Distribution of Solicitation. The 1999 SBIR Program Solicitation is available only via electronic means through the NASA SBIR homepage **(http://sbir.nasa.gov)**, or by requesting a diskette. When requesting a diskette, it is important to specify the platform you are using (PC or Mac), and your complete address. Printed copies of the Solicitation will not be distributed.

Offerors are encouraged to check the SBIR homepage for program updates. Any updates or corrections to the Solicitation will be posted there.

1.5.2 Other Means of Contacting NASA SBIR. Each Strategic Enterprise and field center has a homepage. Please consult these homepages (via NASA's homepage at http://nasa.gov) for more details on the technology requirements within each topic/subtopic areas.

SBIR Program Support Office and Help Line:

1. E-Mail. The e-mail address for contacting NASA to request a diskette containing the Solicitation or to request information is sbir@reisys.com.
2. Facsimile. Inquiries and requests may be made by facsimile to 301-937-0204 and must include the name, address, and telephone and fax numbers of the requester.
3. Telephone. Information about the SBIR program is also available by calling 301-937-0888. Office hours are 8:00 a.m. to 5:00 p.m. Eastern Daylight Time (EDT), Monday through Friday.

NASA SBIR Program Manager:

Specific information requests about the NASA SBIR program that could not be answered by the Help Line should be mailed to:

Paul Mexcur, Program Manager
NASA SBIR/STTR Program Management Office
Building 3, Room 108, Code 710
Goddard Space Flight Center
Greenbelt, MD 20771-0001

1.5.3 Questions About This Solicitation. To ensure fairness, questions relating to the intent and/or content of research topics in this Solicitation cannot be answered during the Phase-I Solicitation period. Only questions requesting clarification of proposal instructions and administrative matters will be answered.

1.5.4 Questions Regarding Proposal Status. Except for an acknowledgment of proposal receipt (to be e-mailed within 30 days of the closing date), information about proposal status will not be available until final selections are announced.

2. Definitions

2.1 Research or Research and Development (R/R&D)

Any activity that is (1) a systematic, intensive study directed toward greater knowledge or understanding of the subject studied, (2) a systematic study directed specifically toward applying new knowledge to meet a recognized need, or (3) a systematic application of knowledge toward the production of useful materials, devices, systems, or methods, including the design, development, and improvement of prototypes and new processes to meet specific requirements.

2.2 Subcontract

Any agreement, other than one involving an employer-employee relationship, entered into by a Federal Government contractor calling for supplies or services required solely for the performance of the original funding agreement. See Sections 3.2.4 Part 9 and 3.3 Part 9 of this Solicitation.

2.3 Socially and Economically Disadvantaged Small Business Concern

A socially and economically disadvantaged SBC is one that is: (1) at least 51% owned by (i) an Indian tribe or a native Hawaiian organization or (ii) one or more socially and economically disadvantaged individuals; and (2) whose management and daily business operations are controlled by one or more socially and economically disadvantaged individuals.

2.4 Socially and Economically Disadvantaged Individual

A member of any of the following groups: Black Americans, Hispanic Americans, Native Americans, Asian-Pacific Americans, Subcontinent-Asian Americans, other groups designated from time to time by SBA to be socially disadvantaged, or any other individual found to be socially and economically disadvantaged by SBA pursuant to Section 8(a) of the Small Business Act, 15 U.S.C. 637(a).

2.5 Small Business Concern

An SBC is one that, at the time of award of Phase-I and Phase-II funding agreements, meets the following criteria:

1. Is independently owned and operated, is not dominant in the field of operation in which it is proposing, has its principal place of business located in the United States, and is organized for profit;

2. Is at least 51% owned, or in the case of a publicly-owned business, at least 51% of its voting stock is owned by United States citizens or lawfully admitted permanent resident aliens; and

3. Has, including its affiliates, a number of employees not exceeding 500 and meets the other regulatory requirements found in 13 CFR Part 121. Business concerns, other than investment companies licensed, or

state development companies qualifying under the Small Business Investment Act of 1958, 15 U.S.C. 661, et seq., are affiliates of one another when, either directly or indirectly, (1) one concern controls or has the power to control the other or (2) a third party controls or has the power to control both. Control can be exercised through common ownership, common management, and contractual relationships. The terms "affiliates" and "number of employees" are defined in greater detail in 13 CFR 121.

Small business concerns include sole proprietorships, partnerships, corporations, joint ventures, associations, or cooperatives. Eligible joint ventures are limited to no more than 49% participation by foreign business entities.

2.6 Women-Owned Small Business

A women-owned SBC is one that is at least 51% owned by a woman or women who also control and operate it. "Control" in this context means exercising the power to make policy decisions. "Operate" in this context means being actively involved in the day-to-day management.

2.7 United States

Means the 50 states, the territories and possessions of the United States, the Commonwealth of Puerto Rico, the Trust Territory of the Pacific Islands, and the District of Columbia.

2.8 Commercialization

Commercialization is a process of developing markets and producing and delivering products or services for sale (whether by the originating party or by others). As used here, commercialization includes both Government and non-government markets.

3. Proposal Preparation Instructions and Requirements

3.1 Fundamental Considerations

3.1.1 Responsiveness to NASA Need. An SBIR Phase-I proposal must present a scientific or technical innovation that addresses a need as described in a specific subtopic. If the proposal as described in the Project Summary (Form 9B) is judged to be non-responsive to the subtopic, it will be rejected without evaluation. SBIR projects should address NASA needs requiring significant scientific or technical innovation, either experimental or theoretical.

3.1.2 Proposal Objective. A Phase-I proposal must describe the research effort needed to investigate the feasibility of the proposed scientific or technical innovation. The objective of the Phase-I effort must be to determine whether the innovation has sufficient technical merit for proceeding into Phase-II R/R&D.

The objective of Phase-II is to continue the R/R&D effort from Phase-I. Only NASA Phase-I awardees may compete for Phase-II projects.

3.1.3 Unacceptable Objectives. Proposed efforts directed toward market research; commercial development of existing products or proven concepts; straightforward engineering design for packaging or adaptation to specific applications; laboratory evaluations; and modifications of existing products without innovative changes are examples of projects that are not acceptable under the NASA SBIR program.

3.1.4 Multiple Proposal Submissions. An offeror may submit **different** proposals in response to any number of subtopics, but every proposal must be based on an unique innovation, must be limited in scope to just one subtopic, and may be submitted only under that subtopic.

3.1.5 Similar Proposals. Submitting substantially equivalent proposals to several subtopics is not permitted and may result in all such proposals being rejected without evaluation.

3.1.6 End Deliverables. The deliverable item at the end of a Phase-I contract shall be a professional quality report that justifies, validates, and defends the experimental and theoretical work accomplished. Furthermore, this report must demonstrate the basis for judgments about technical merit and feasibility of the innovation presented in the Phase-I proposal. It should connect the Phase-I results to Phase-II follow-on R/R&D and commercial applications. Delivery of a product or service with the Phase-I report may be desirable, but it is not a requirement.

Deliverable items for Phase-II contracts shall include products or services in addition to professional quality reports of further developments or applications of the Phase-I results. These deliverables may include prototypes, models, software, or complete products or services. The reported results of Phase-II must address and provide the basis for validating the innovation and the potential for implementation of commercial applications.

3.2 Phase-I Proposal Requirements

3.2.1 General Requirements:

Page Limitation. A Phase-I SBIR proposal shall not exceed a total of 25 standard 8 1/2 x 11 inch (21.6 x 27.9 cm) pages, including cover page, budget, and all enclosures or attachments. Margins should be 1.0 inch (2.5 cm). All material submitted, except required listing of Phase-II awards (Section 3.2.6), will be included in the page count. Samples, videotapes, slides, or other ancillary items will not be accepted. Offerors are requested not to use the entire 25-page allowance unless necessary**. Proposals exceeding the 25 page limitation will be rejected during administrative screening.** The program would prefer proposals prepared on both sides of paper, if possible.

Type Size. No type size smaller than 10 point is to be used for text or tables, except as legends on reduced drawings. Proposals prepared with smaller font sizes will be rejected without consideration.

Brevity and Organization. The proposal should be focused, concise, and organized in accordance with the Solicitation requirements.

3.2.2 Format Requirements. All required items of information must be covered in the following prescribed order. The space allocated to each part of the technical proposal will depend on the project chosen and the offeror's approach.

Each proposal submitted must contain the following in the order presented:

- Proposal Cover (Form 9A), signed in ink, as page 1.
- Project Summary (Form 9B), as page 2.
- Technical Proposal (12 Parts), including all graphics, and starting at page 3 with a table of contents.
- Summary Budget (Form 9C), signed in ink.

3.2.3 Proposal Cover and Project Summary:

Page 1: Proposal Cover (Form 9A). A copy of the Proposal Cover sheet is provided in Section 9. Each offeror shall provide complete information for each item and submit the form as required in Section 6. The proposal title shall be concise and descriptive of the proposed effort. The title should not use acronyms or words like "Development of" or "Study of." The NASA research topic title must not be used as the proposal title.

Page 2: Project Summary (Form 9B). A copy of the Project Summary sheet is provided in Section 9. Offerors shall provide complete information for each item and submit Form 9B as required in Section 6. This technical abstract (limited to 200 words) shall summarize the implications of the approach and the anticipated results of both Phase-I and Phase-II. Potential commercial applications of the technology should also be presented.

Note: The Proposal Cover and the Project Summary (Abstract) are public information, and the Government may disclose them. Do not include proprietary information on these forms.

3.2.4 Technical Proposal. The proposal shall not contain any budget data and must consist of all twelve parts numbered and in the prescribed order. A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening. Parts that are not applicable must be noted as "Not Applicable." Offerors are advised to avoid including proprietary information (Section 5.4.1).

Part 1: Table of Contents. Page 3 of the proposal shall begin with a brief table of contents indicating the page numbers of each of the sections of the proposal.

Part 2: Identification and Significance of the Innovation. The first paragraph of Part 2 shall contain (1) a clear and succinct statement of the specific innovation proposed and why it is an innovation, and (2) a brief explanation of how the innovation is relevant and important to meeting the technology need described in the subtopic. The initial paragraph shall contain no more than 200 words. **NASA will reject proposals that lack this introductory paragraph**. In subsequent paragraphs, Part 2 may also include appropriate background and elaboration to explain the proposed innovation.

Part 3: Technical Objectives. State the specific objectives of the Phase-I R/R&D effort including the technical questions that must be answered to determine the feasibility of the proposed innovation.

Part 4: Work Plan. Phase-I R/R&D should address the objectives and questions cited in Part 3. The work plan should indicate what will be done, where it will be done, and how it will be done. The methods planned to achieve each objective or task should be discussed in detail. Schedules, task descriptions and assignments, resource allocations, estimated task hours for each key personnel, and planned accomplishments including project milestones shall be included.

Part 5: Related R/R&D. Describe significant current and/or previous R/R&D that is directly related to the proposal including any conducted by the principal investigator or by the offeror. Describe how it relates to the proposed effort and any planned coordination with outside sources. The offeror must persuade reviewers of his or her awareness of key recent R/R&D conducted by others in the specific subject area. At the offeror's option, this section may include concise bibliographic references in support of the proposal if they are confined to activities directly related to the proposed work.

Part 6: Key Personnel and Bibliography of Directly Related Work. Identify key personnel involved in Phase-I activities. Key personnel are the principal investigator and other individuals whose expertise and functions are essential to the success of the project. Provide bibliographic information including directly related education and experience.

This part shall also establish and confirm the eligibility of the principal investigator (Section 1.4.3), and indicate the extent to which other proposals recently submitted or planned for submission in 1999 and existing projects commit the time of PI concurrently with this proposed activity. Any attempt to circumvent the restriction on PIs working more than half-time for an academic or a non-profit organization by substituting an ineligible PI will result in rejection of the proposal.

Part 7: Relationship with Phase-II or Future R/R&D. State the anticipated results of the proposed R/R&D effort if the project is successful (through Phase-I and Phase-II). Discuss the significance of the Phase-I effort in providing a foundation for the Phase-II R/R&D continuation.

Part 8: Company Information and Facilities. Provide adequate information to allow the evaluators to assess the ability of the SBC team to carry out the proposed Phase-I and projected Phase-II and Phase-III activities. The offeror should describe the relevant facilities and equipment currently available, and those to be purchased, to support the proposed activities. NASA will not fund the acquisition of equipment, instrumentation, or facilities under SBIR Phase-I contracts as a direct cost (Section 5.14)

The capability of the offeror to perform the proposed activities and bring a resulting product or service to market must be indicated. Qualifications of the offeror and its principals in marketing-related products or services or in raising capital should be presented.

If an offeror proposes the use of unique or one-of-a-kind Government facilities, a statement, describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate

Government official must be included with the proposal. Proposals lacking this signed statement may be rejected without evaluation. If the proposer does not require the use of Government facilities or equipment, the proposer shall so state in this part of the proposal.

Part 9: Subcontracts and Consultants. Up to one-third of the research and/or analytical work (contract cost less fee) in Phase-I may be conducted under subcontract or other business arrangements. If the offeror intends such arrangements, they should be described in detail including functions, services, number of hours and labor rates, and extent of effort to be provided. The proposal must include a signed statement by each participating organization or individual that they will be available at the times required for the purposes and extent of effort described in the proposal. Failure to provide certification(s) may result in rejection of the proposal.

Part 10: Commercial Applications Potential. The commercial potential of the proposed SBIR project is a significant evaluation factor (Section 4.1.2). Therefore, offerors will discuss in this section the broad commercial applications for their project results and plans to bring the technology to commercial application. Offerors should discuss the following:

1. The specific commercial products or services contemplated and the corresponding target market niche;
2. Expected unique competitive advantage of the commercial products or services;
3. Nature of the corresponding contemplated commercial venture;
4. Importance of the contemplated commercial venture to the offeror's current competitive position and to its strategic planning; and
5. The offeror’s capability and plans to bring the necessary physical, personnel, and financial resources to bear, in a timely way, to result in a viable commercial venture in the near term subsequent to Phase-II (if awarded).

Part 11: Similar Proposals and Awards. A firm may elect to submit proposals for essentially equivalent work under other program solicitations. However, NASA will not fund duplicate proposals for essentially equivalent work under any Government program. The offeror will inform NASA of related proposals and awards and must certify on the Proposal Cover (Form 9A) whether the offeror: (a) has received Federal Government awards for related work; or (b) has submitted currently active proposals for similar work under other Federal Government program solicitations; or (c) intends to submit proposals for such work to other agencies during 1999. For all such cases, the following information is required:

1. The name and address of the agencies to which proposals have been or will be submitted, or from which awards have been received;
2. Dates of such proposal submissions or awards;
3. Title, number, and date of solicitations under which proposals have been or will be submitted or awards received;
4. The specific applicable research topic for each such proposal submitted or award received;
5. Titles of research projects;
6. Name and title of the principal investigator/project manager for each proposal that has been or will be submitted or award received.

Note: Lack of the required certification on Form 9A or failure to declare the existence of related, similar or duplicate awards or proposals will result in rejection of the offer or loss of an award. If no such awards have been received or no such proposals have been submitted or are intended, the offeror shall so state in this part of the proposal.

Part 12: Previous NASA SBIR Awards. Provide a list of NASA SBIR Phase-I and Phase-II awards received, showing contract numbers, the year of award, Phase-I or Phase-II, the NASA Installations making the award, and project titles. If no prior NASA awards have been received, the offeror shall so state in this part of the proposal.

3.2.5 Proposed Budget:

1) **Summary Budget (Form 9C).** Offerors shall complete the Summary Budget, following the instructions provided with the form (Section 9) and include it and any explanation sheets, if needed, as the last page(s) of

the proposal. Information shall be submitted to explain the offeror's plans for use of the requested funds to enable NASA to determine whether the proposed budget is fair and reasonable.

2) **Property.** NASA will not fund facility acquisition under Phase-I (Section 5.14). Proposed costs for materials may be included. "Materials" means property that may be incorporated or attached to a deliverable end item or that may be consumed or expended in performing the contract. It includes assemblies, components, parts, raw materials, and small tools that may be consumed in normal use. Any purchase of equipment or products under an SBIR contract using NASA funds should be American-made to the extent possible.

3) **Travel.** Travel during Phase-I is not normally allowed to prove technical merit and feasibility of the proposed innovation. However, where the offeror deems travel to be essential for these purposes, it is necessary to limit it to one person, one trip to the sponsoring NASA installation. Proposed travel must be described as to purpose and benefits in proving feasibility, and is subject to negotiation and approval by the contracting officer. Trips to conferences are not allowed under the Phase-I contract.

4) **Profit.** A profit or fee may be included in the proposed budget as noted in Section 5.9.

5) **Cost Sharing.** See Section 5.8.

3.2.6 Addendum for Prior SBIR Phase-II Awards. The Small Business Administration requires offerors, who have received more than 15 Phase-II awards from all agencies in the prior 5 fiscal years, to report those awards and their progress toward commercialization. The listing of awards shall be included in a separate "Addendum: Phase-II History" that will not be counted against the Phase-I 25-page proposal limit. The Addendum should be concise. Information for each Phase-II contract shall include:

(1) Name of awarding agency
(2) Date of award and date of completion
(3) Funding agreement number and amount
(4) Topic or subtopic name
(5) Project title
(6) Sources, dates and amounts of federal and/or private sector Phase-III follow-on funding agreements
(7) Post-Phase-II commercialization activities, including development, marketing, sales, and projections

Note: Companies with Prior NASA SBIR Awards

NASA has instituted a comprehensive commercialization survey/data gathering process for companies that have had prior NASA SBIR awards. Information received from SBIR companies completing the survey is kept confidential, and will not be made public except in broad aggregate, with no company specific attribution.

Responding to the survey is strictly voluntary. However, the SBIR Source Selection Official does see the information contained within the survey as adding to the program's ability to use past performance in decision making.

If you have not completed a survey, or if you would like to update a previously submitted response, please contact Jack Yadvish at NASA Headquarters by email at jyadvish@mail.hq.nasa.gov, or phone at 202-358-1981.

3.3 Phase-II Proposal Requirements

The Phase-I contract will serve as a request for proposal (RFP) for the Phase-II follow-on project. Phase-II proposals are more comprehensive than those required for Phase-I. Submission of a Phase-II proposal is strictly voluntary and NASA assumes no responsibility for any proposal preparation expenses.

Proposal Contents. Proposals shall be prepared in the following order. Failure to include any requested information in the proposal may make it non-responsive to the RFP. The proposal shall not contain any budget data and must consist of all 13 parts numbered and in following order. A proposal omitting any part will be considered non-responsive to this Solicitation and may be rejected during administrative screening.

Part 1: Proposal Cover. (Form provided by awarding Center)

Part 2: Project Summary. (Form provided by awarding Center)

Part 3: Table of Contents.

Part 4: Results of the Phase-I Project. Briefly describe how Phase-I has proven the feasibility of the innovation, provided a rationale for both NASA and commercial applications, and demonstrated the ability of the offeror to conduct R/R&D.

Part 5: Technical Objectives, Approach and Work Plan. Define the specific objectives of the Phase-II research and technical approach; and provide a work plan defining specific tasks, performance schedules, milestones, and deliverables.

Part 6: Company Information. Describe the capability of the firm to carry out Phase-II and Phase-III activities including its organization, operations, number of employees, R/R&D capabilities, and experience relevant to the work proposed.

Part 7: Facilities and Equipment. This section shall provide adequate information to allow the evaluators to assess the ability of the SBC to carry out the proposed Phase-II activities. The offeror should describe the relevant facilities and equipment currently available, and those to be purchased, to support the proposed activities. NASA will not fund the acquisition of equipment, instrumentation, or facilities under SBIR Phase-II contracts as a direct cost (Section 5.14).

If an offeror proposes the use of unique or one-of-a-kind Government facilities, a statement, describing the uniqueness of the facility and its availability to the offeror at specified times, signed by the appropriate Government official must be included with the proposal. Proposals lacking this signed statement may be rejected without evaluation. If the proposer does not require the use of Government facilities or equipment, the proposer shall so state in this part of the proposal.

Part 8: Key Personnel. Identify the key personnel for the project, confirm their availability for Phase-II, and discuss their qualifications in terms of education, work experience, and accomplishments that are relevant to the project. For any PI, who is an employee of an academic or non-profit organization, provide a release statement as described in Section 1.4.3 of this Solicitation.

Part 9: Consultants and Subcontracts. Describe in detail any subcontracting, consultant, or other business arrangements. The proposal must include certifications by each participating organization or individual that they will be available at the times required for the purposes and extent of effort described in the proposal. Failure to provide subcontractor/consultant certifications may result in rejection of the proposal**.**

For Phase-II, a minimum of one-half of the work (contract cost less profit) must be performed by the proposing SBC unless approved in writing by the contracting officer.

Part 10: Commercialization and Phase-III Plans. Describe plans for commercialization (Phase-III) in terms of each of the following areas:

(1) Product or Service Commercial Feasibility: Provide a description of the (a) contemplated commercial product and/or service, the corresponding commercial venture, and the unique competitive advantage of both; and (b) technical obstacles to commercial applications, as well as plans to address them.

(2) Market Feasibility and Competition: Describe: (a) the target market niche including the distinction between U.S. Government and other markets; (b) estimated potential market size in terms of revenues to be realized by the offeror from U.S. Government markets and, separately, from other markets; (c) competitive environment in terms of present and likely competing similar and alternative technologies, and corresponding competing domestic and foreign entities; (d) significant developments within the targeted business sector; and (e) offeror's ability, if any, to protect relevant technology with patents or rights to exclusive access.

(3) Strategic Relevance to the Offeror: Describe the relevance of the targeted commercial venture to the offeror's: (a) current business segments; (b) relative position with respect to its competitors; and (c) strategic planning for the next 5 years.

(4) Key Management, Technical Personnel and Organizational Structure: Describe: (a) the skills and experience of key management and technical personnel relevant to bringing innovative technology to commercial application, (b) current organizational structure, and (c) plans and timeline for obtaining the balance of all necessary key business development expertise and other staffing requirements.

(5) Production and Operations: Describe: (a) business development progress to date regarding the contemplated commercial venture; (b) obstacles, plans, and associated milestones regarding all key business development elements; and (c) sources and components of private physical resources committed to date and plans for obtaining the balance of the necessary physical resources.

(6) Financial Planning: Describe: (a) the amounts and sources of private financial resources expended and committed to date with respect to the technology development project, and with respect to business development of the targeted commercial venture; (b) significant requirements of potential investors, creditors, and insurers of the venture; (c) proforma statement of cash flow with respect to the targeted commercial venture that includes best estimates of at least the following major components and timing thereof: capital investment, revenues, principal and interest payments, depreciation of relevant assets, other operating expenses; and (d) evidence of the offeror's current financial strength (audited or unaudited financial statements may be appended to address this).

Part 11: Capital Commitments Supporting Phase-II and Phase-III. Describe and document capital commitments from non-SBIR sources or from internal funds for pursuit of Phase-II and Phase-III. Offerors for Phase-II contracts are strongly urged to obtain valid non-SBIR funding support commitments for follow-on Phase-III activities and additional support of Phase-II from parties other than the proposing firm. Valid funding support commitments must provide that a specific, substantial amount will be made available to the firm to pursue the stated Phase-II and/or Phase-III objectives. They must indicate the source, date, and conditions or contingencies under which the funds will be made available. Alternatively, self-commitments of the same type and magnitude that are required from outside sources can be considered. If Phase-III will be funded internally, offerors should describe their financial position.

Evidence of funding support commitments from outside parties must be provided in writing to the proposing entity and should accompany the Phase-II proposal. Letters of commitment should specify available funding commitments, other resources to be provided, and any contingent conditions. Expressions of technical interest by such parties in the Phase-II research or of potential future financial support are insufficient and will not be accepted as support commitments by NASA.

Part 12: Related R/R&D. Describe R/R&D related to the proposed work and affirm that the proposed objectives have not already been achieved and that the same development is not presently being pursued elsewhere under contract to the Government.

Part 13: Proposal Pricing. Special instructions for pricing the Phase-II proposal will be provided in the Phase-I contract and may be provided by the contracting officer.

4. Method of Selection and Evaluation Criteria

4.1 Phase-I Proposals

Proposals judged to be responsive to the administrative requirements of this Solicitation and having a reasonable potential of meeting a NASA need, as evidenced by the abstract, will be evaluated on a competitive basis.

4.1.1 Evaluation Process. Proposals should provide all information needed for complete evaluation and evaluators are not expected to seek additional information. Evaluations will be performed by NASA scientists and engineers and by qualified experts outside of NASA (including industry, academia, and other Government agencies) as required to determine or verify the merit of a proposal. Offerors should not assume that evaluators are acquainted with the firm, key individuals, or with any experiments or other information. Any pertinent references or publications should be noted in Part 5 of the technical proposal.

4.1.2 Phase-I Evaluation Criteria. NASA will give primary consideration to the scientific and technical merit and feasibility of the proposal and its benefit to NASA. Each proposal will be judged and scored on its own merits using the factors described below:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on whether it offers a clearly innovative and feasible technical approach to the NASA problem area described in the subtopic. Specific objectives, approaches and plans for developing and verifying the innovation must demonstrate a clear understanding of the problem and the current state-of-the-art. The degree of understanding and significance of the risks involved in the proposed innovation must be presented.

Factor 2. Experience, Qualifications and Facilities
The technical capabilities and experience of the principal investigator or project manager, key personnel, staff, consultants and subcontractors, if any, are evaluated for consistency with the research effort and their degree of commitment and availability. The necessary instrumentation or facilities required must be shown to be adequate and any reliance on external sources, such as Government Furnished Equipment or Facilities, addressed (Section 5.14).

Factor 3. Effectiveness of the Proposed Work Plan
The work plan will be reviewed for its comprehensiveness, effective use of available resources, cost management and proposed schedule for meeting the Phase-I objectives. The methods planned to achieve each objective or task should be discussed in detail.

Factor 4. Commercial Merit and Feasibility
The proposal will be evaluated for any potential commercial applications in the private sector or for use by the Federal Government.

Scoring of Factors and Weighting: The sum of the scores for Factors 1, 2 and 3 constitutes the numerical value for the Technical Merit of a proposal. Factor 1 is about twice the weight of Factors 2 and 3. The score for Commercial Merit will be in the form of an adjectival rating (Excellent, Very Good, Average, Below Average, Poor, Insufficient Data). Technical Merit score is most significant in Phase-I. In proposals of equal Technical Merit, Commercial Merit can be a deciding factor. Commercial Merit rises in significance for Phase-II consideration.

4.1.3 Selection. After a proposal is evaluated, it will be ranked relative to all other proposals. Selection decisions will consider the recommendations from all Centers, Strategic Enterprises, overall NASA priorities, and program balance. An offeror’s past performance evaluations under prior NASA contracts may be reviewed by the Source Selection Official and considered in making the final selection decision. The SBIR Source Selection Official has the final authority for choosing the specific proposals for contract negotiation.

Firms selected for negotiations that may lead to an award will be notified by e-mail. The list of selections will be announced in a NASA press release and will also be posted on the NASA SBIR web site **(http://sbir.nasa.gov)**. Selected firms will receive a formal notification letter that identifies the Contracting Officer at the NASA Center responsible for negotiating the Phase-I contract.

4.2 Phase-II Proposals

4.2.1 Evaluation Process. The Phase-II evaluation process is similar to the Phase-I process. Each proposal will be reviewed by NASA scientists and engineers and by qualified experts outside of NASA as needed. In addition, those proposals with high technical merit will be reviewed for commercial merit. NASA uses a peer review panel to evaluate commercial merit. Panel membership will include non-NASA personnel experts in business development and technology commercialization.

4.2.2 Evaluation Factors. The evaluation of Phase-II proposals under this Solicitation will apply the following factors:

Factor 1. Scientific/Technical Merit and Feasibility
The proposed R/R&D effort will be evaluated on its innovativeness, originality, and technical payoff potential if successful, including the degree to which Phase-I objectives were met, the feasibility of the innovation, and whether the Phase-I results indicate a Phase-II project is appropriate.

Factor 2. Future Importance and Value to NASA
The eventual value of the product, process, or technology results to the NASA mission will be assessed.

Factor 3. Capability of the Small Business Concern
NASA will assess the capability of the SBC to conduct Phase-II based on (a) the validity of the project plans for achieving the stated goals; (b) the qualifications and ability of the project team (Principal Investigator/Project Manager, company staff, consultants and subcontractors) relative to the proposed research; and (c) the availability of any required equipment and facilities.

Factor 4. Commercial Potential. Consideration will be given to the following:

(1) Commercial potential of the technology: This includes an assessment of the offeror's ability to demonstrate: (a) a specific, well-defined commercial product or service based on the technology to be developed; (b) a realistic target market niche of sufficient size; (c) that the targeted commercial product or service has strong potential for uniquely meeting a well-defined need within the target market niche; and (d) a commitment of significant private financial, physical, and technical personnel resources.

(2) Demonstrated commercial intent of the offeror: This includes an assessment of: (a) the importance of the targeted commercial venture to the offeror's current business and strategic planning; (b) a targeted commercial venture that does not rely on continued U.S. Government markets; and (c) the adequacy of all resource commitments for Phase-III development of the technology to a state of readiness for commercial application.

(3) Capability of the offeror to bring successfully developed technology to commercial application: This includes assessment of the offeror's ability to demonstrate: (a) the offeror's past success in bringing SBIR and other innovative technologies to commercial application; (b) well-thought-out business planning; (c) strong likelihood of the offeror's bringing the remaining necessary private financial, physical, personnel and other resources to bear in a timely way to achieve commercial application of the technology in the not too distant term subsequent to Phase-II; and (d) the strength of the current and continued financial viability of the offeror.

In applying these commercial criteria, NASA will assess proposal information in terms of credibility, objectivity, reasonableness of key assumptions, independent corroborating evidence, internal consistency, demonstrated awareness of key risk areas and critical business vulnerabilities, and other indicators of sound business analysis and judgment.

4.2.3 Evaluation and Selection. Factors 1, 2, and 3 will be scored numerically. Factors 2 and 3 are of equal importance, being equivalent in total to Factor 1. The sum of the scores for Factors 1, 2, and 3 will comprise the Technical Merit score. Proposals receiving high numerical scores will be evaluated and rated for their commercial potential using the criteria listed in Factor 4 and by applying the same adjectival ratings as set forth for Phase-I proposals.

Each NASA Installation managing Phase-I projects will use these factors to evaluate the Phase-II proposals it receives that are responsive to the Phase-II RFP. Final selections will be based on recommendations from all Installations and Strategic Enterprises; assessments of project value to NASA's overall programs and plans; and any other evaluations or assessments (particularly of commercial potential) that may become available to the Source Selection Official. An offeror's past performance evaluations under prior NASA contracts may be reviewed by the Source Selection Official and considered in making the final selection decision.

4.3 Debriefing of Unsuccessful Offerors

After Phase-I and Phase-II selection decisions have been announced, debriefings for unsuccessful proposals will be available to the offeror's corporate official or designee via e-mail. Telephone requests for debriefings will not be accepted. Debriefings are not opportunities to reopen selection decisions. They are intended to acquaint the offeror with perceived strengths and weaknesses of the proposal and perhaps identify constructive future action by the offeror.

Debriefings will not disclose the identity of the proposal evaluators nor provide proposal scores, rankings in the competition, or the content of, or comparisons with other proposals.

4.3.1 Phase-I Debriefings. For Phase-I proposals, any request for a debriefing must be made via e-mail to sbir@reisys.com, within 60 days after the selection announcement. Late requests will not be honored.

4.3.2 Phase-II Debriefings. To request debriefings on Phase-II proposals, offerors must request via e-mail to the Procurement Point of Contact at the appropriate NASA Center (not the SBIR Program Manager) within 60 days after selection announcement. Late requests will not be honored.

5. Considerations

5.1 Awards

5.1.1 Availability of Funds. Both Phase-I and Phase-II awards are subject to availability of funds. NASA has no obligation to make any specific number of Phase-I or Phase-II awards based on this Solicitation, and may elect to make several or no awards in any specific technical topic or subtopic.

NASA plans to announce the selection of approximately 270 proposals resulting from this Solicitation, for negotiation of Phase-I contracts with values not exceeding $70,000. Following contract negotiations and awards, Phase-I contractors will have up to 6 months to carry out their programs, prepare their final reports, and submit Phase-II proposals. NASA intends that all Phase-I projects selected will be placed under contract by late 1999.

NASA anticipates that approximately 40 percent of the successfully completed Phase-I projects from the SBIR 99-1 Solicitation will be selected for Phase-II. Phase-II agreements are fixed-price contracts with performance periods not exceeding 24 months and funding not exceeding $600,000.

5.1.2 Contracting. Fixed-price contracts will be issued for Phase-I and simplified contract documentation will be employed. From the time of proposal selection until the award of a contract, only the Contracting Officer is authorized to commit the Government, and all communications must be through the Contracting Officer.

> NASA is not responsible for any monies expended by the offeror before award of any contract resulting from this Solicitation.

5.2 Phase-I Reporting

An interim progress report is required when the invoice is submitted at project mid-point in accordance with the payment schedule (Section 5.3). This report shall document progress made on the project and activities required for completion to provide NASA the basis for determining whether the payment is warranted.

A final report must be submitted to NASA upon completion of the Phase-I R/R&D effort in accordance with contract provisions. It shall elaborate the project objectives, work carried out, results obtained, and assessments of technical merit and feasibility. The final report shall include a single page project summary as the first page, in a format provided in the Phase-I contract, identifying the purpose of the R/R&D effort and describing the findings and results, including the degree to which the Phase-I objectives were achieved, and whether the results justify Phase-II continuation. The potential applications of the project results in Phase-III either for NASA or commercial purposes shall also be described. The project summary is to be submitted without restriction for NASA publication. Language used in the Phase-I report may be used verbatim in the Phase-II proposal.

5.3 Payment Schedule for Phase-I

Payments can be authorized as follows: one-third at the time of award, one-third at project mid-point after award, and the remainder upon acceptance of the final report by NASA. The first two payments will be made 30 days after receipt of valid invoices. The final payment will be made 30 days after acceptance of the final report and other deliverables as required by the contract. Electronic funds transfer will be employed and offerors will be required to submit account data if selected for contract negotiations.

5.4 Treatment and Protection of Proposal Information

In the evaluation and handling of proposals, NASA will make every effort to protect the confidentiality of the proposals and their evaluations. All proposals will be converted into an electronic format (Section 6.2) and placed on a secure, limited access NASA Internet server.

5.4.1 Proprietary Information. It is NASA's policy to use information (data) included in proposals for evaluation purposes only. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. If information consisting of a trade secret, proprietary commercial or financial information, or private personal information is provided in an SBIR proposal, NASA will treat in confidence the proprietary information provided the following legend appears on the title page of the proposal:

> "For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that if a funding agreement is awarded to the offeror as a result of or in connection with the submission of this data, the Government shall have the right to duplicate, use or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages _____ of this proposal."

Do not label the entire proposal proprietary. The Project Summary (Form 9B), should not contain proprietary information**.**

5.4.2 Non-NASA Reviewers. In addition to Government personnel, NASA at its discretion and in accordance with 18-15.413-2 of the NASA FAR Supplement, may utilize qualified individuals from outside the Government in the proposal review process. Any decision to obtain an outside evaluation shall take into consideration requirements for the avoidance of organizational or personal conflicts of interest and the competitive relationship, if any, between the prospective contractor or subcontractor(s) and the prospective outside evaluator. Any such evaluation will be under agreement with the evaluator that the information (data) contained in the proposal will be used only for evaluation purposes and will not be further disclosed.

Release of Proposal Information. In submitting a proposal, the offeror agrees to permit the Government to disclose publicly the information contained on the Proposal Cover (Form 9A) and the Project Summary (Form 9B). Other proposal information (data) is considered to be the property of the offeror, and NASA will protect it from public disclosure to the extent permitted by law.

5.4.4 Final Disposition of Proposals. The Government retains ownership of proposals accepted for evaluation, and such proposals will not be returned to the offeror. Copies of all evaluated Phase-I proposals will be retained for one year after the Phase-I selections have been made, after which time unsuccessful proposals will be destroyed. Successful proposals will be retained in accordance with contract file regulations.

5.5 Rights in Data Developed Under SBIR Contracts

Rights to data used in, or first produced under, any Phase-I or Phase-II contract are specified in the clause at FAR 52.227-20, Rights in Data--SBIR Program. The clause provides for rights consistent with the following:

5.5.1. Non-Proprietary Data. Some data of a general nature are to be furnished to NASA without restriction (i.e., with unlimited rights) and may be published by NASA. These data will normally be limited to the project summaries accompanying any periodic progress reports and the final reports required to be submitted. The requirement will be specifically set forth in any contract resulting from this Solicitation.

5.5.2 Proprietary Data. When data that is required to be delivered under an SBIR contract qualifies as “proprietary,” *i.e*., either data developed at private expense that embody trade secrets or are commercial or financial and confidential or privileged, or computer software developed at private expense that is a trade secret, the contractor, if the contractor desires to continue protection of such proprietary data, shall not deliver such data to the Government, but instead shall deliver form, fit, and function data.

5.5.3 Non-Disclosure Period. The Government, for a period of 4 years from acceptance of all items to be delivered under an SBIR contract, shall use SBIR data, *i.e*., data first produced by the contractor in performance of the contract, where such data are not generally known, and which data without obligation as to its confidentiality have not been made available to others by the contractor or are not already available to the Government, agrees to use these data for Government purposes. These data shall not be disclosed outside the Government (including disclosure for procurement purposes) during the 4-year period without permission of the contractor, except that such data may be disclosed for use by support contractors under an obligation of confidentiality. After the 4-year period, the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, but the Government is relieved of all disclosure prohibitions and assumes no liability for unauthorized use by third parties.

5.6 Copyrights

Subject to certain licenses granted by the contractor to the Government, the contractor receives copyright to any data first produced by the contractor in the performance of an SBIR contract.

5.7 Patents

The contractor may normally elect title to any inventions made in the performance of an SBIR contract. The Government receives a nonexclusive license to practice or have practiced for or on behalf of the Government each such invention throughout the world. To the extent authorized by 35 U.S.C. 205, the Government will not make public any information disclosing such inventions for a reasonable time to allow the contractor to file a patent application.

5.8 Cost Sharing

Cost sharing is permitted but not required for proposals under this Program Solicitation. Cost sharing will not be a factor in proposal evaluation except as a consideration for Phase-II/III commitments discussed in Section 3.3 Part 11. If included, cost sharing should be shown in the summary budget but not included in items labeled "Amount Requested." No profit will be paid on the cost-sharing portion of the contract.

5.9 Profit or Fee

Both Phase-I and Phase-II SBIR contracts should include a reasonable profit. The reasonableness of proposed profit is determined by the Contracting Officer during contract negotiations.

5.10 Joint Ventures and Limited Partnerships

Both joint ventures and limited partnerships are permitted, provided the entity created qualifies as a SBC in accordance with the definition in Section 2.5. A statement of how the workload will be distributed, managed, and charged should be included in the proposal. A copy or comprehensive summary of the joint venture agreement or partnership agreement should be appended to the proposal. This will not count as part of the 25 page limit for the Phase-I proposal.

5.11 Similar Awards and Prior Work

If an award is made pursuant to a proposal submitted under this Program Solicitation, the firm will be required to certify that it has not previously been paid nor is currently being paid for essentially equivalent work by any agency of the Federal Government. Failure to acknowledge or report similar or duplicate efforts can lead to the termination of contracts or other actions.

5.12 Contractor Commitments

Upon award of a contract, the contractor will be required to make certain legal commitments through acceptance of numerous clauses in the Phase-I contract. The outline that follows illustrates the types of clauses that will be included. This is not a complete list of clauses to be included in Phase-I contracts, nor does it contain specific wording of these clauses. Copies of complete provisions will be made available prior to contract negotiations.

5.12.1 Standards of Work. Work performed under the contract must conform to high professional standards. Analyses, equipment, and components for use by NASA will require special consideration to satisfy the stringent safety and reliability requirements imposed in aerospace applications.

5.12.2 Inspection. Work performed under the contract is subject to Government inspection and evaluation at all reasonable times.

5.12.3 Examination of Records. The Comptroller General (or a duly authorized representative) shall have the right to examine any directly pertinent records of the contractor involving transactions related to the contract.

5.12.4 Default. The Government may terminate the contract if the contractor fails to perform the contracted work.

5.12.5 Termination for Convenience. The contract may be terminated by the Government at any time if it deems termination to be in its best interest, in which case the contractor will be compensated for work performed and for reasonable termination costs.

5.12.6 Disputes. Any dispute concerning the contract that cannot be resolved by mutual agreement shall be decided by the contracting officer with right of appeal.

5.12.7 Contract Work Hours. The contractor may not require a non-exempt employee to work more than 40 hours in a work week unless the employee is paid for overtime.

5.12.8 Equal Opportunity. The contractor will not discriminate against any employee or applicant for employment because of race, color, religion, age, sex, or national origin.

5.12.9 Affirmative Action for Veterans. The contractor will not discriminate against any employee or applicant for employment because he or she is a disabled veteran or veteran of the Vietnam era.

5.12.10 Affirmative Action for Handicapped. The contractor will not discriminate against any employee or applicant for employment because he or she is physically or mentally handicapped.

5.12.11 Officials Not to Benefit. No member of or delegate to Congress shall benefit from the SBIR contract.

5.12.12 Covenant Against Contingent Fees. No person or agency has been employed to solicit or to secure the contract upon an understanding for compensation except bona fide employees or commercial agencies maintained by the contractor for the purpose of securing business.

5.12.13 Gratuities. The contract may be terminated by the Government if any gratuities have been offered to any representative of the Government to secure the contract.

5.12.14 Patent Infringement. The contractor shall report to NASA each notice or claim of patent infringement based on the performance of the contract.

5.12.15 American-Made Equipment and Products. Equipment or products purchased under an SBIR contract must be American-made whenever possible.

5.13 Additional Information

5.13.1 Precedence of Contract Over Solicitation. This Program Solicitation reflects current planning. If there is any inconsistency between the information contained herein and the terms of any resulting SBIR contract, the terms of the contract are controlling.

5.13.2 Evidence of Contractor Responsibility. Before award of an SBIR contract, the Government may request the offeror to submit certain organizational, management, personnel, and financial information to establish responsibility of the offeror. Contractor responsibility includes all resources required for contractor performance, i.e., financial capability, work force, and facilities.

5.13.3 Classified Proposals. NASA will not accept classified proposals.

5.13.4 Unsolicited Proposals. Unsolicited proposals will not be accepted under the SBIR program. Unsolicited proposals include proposals unrelated to a subtopic need.

5.14 Property

In accordance with the Federal Acquisition Regulations (FAR) Part 45, it is NASA's policy not to provide facilities (capital equipment, tooling, test and computer facilities, etc.) for the performance of work under contract. An SBC will furnish its own facilities to perform the proposed work as an indirect cost to the contract. Special tooling required for a project may be allowed as a direct cost.

When an SBC cannot furnish its own facilities to perform required tasks, an SBC may propose to acquire the use of commercially available facilities. Rental or lease costs may be considered as direct costs as part of the total funding for the project. If unique requirements force an offeror to acquire facilities under a NASA contract, they will be purchased as Government Furnished Equipment (GFE) and titled to the Government.

An offeror may propose the use of unique or one-of-a-kind NASA facilities if essential for the research. Offerors requiring a NASA facility must clearly document and certify that there is no commercially available facility to perform the R&D. It may be difficult, however, to ensure availability, and non-availability may lead to non-selection. Should an offeror propose the use of unique or one-of-a-kind NASA facilities essential for the R/R&D, an agreement with the responsible installation is required and costs for their use will be determined by the installation. These costs may be chargeable in accordance with the Government property clause of the contract. Total contract costs must not exceed the Phase-I and Phase-II funding limits given in this Solicitation (Section 5.1).

6. Submission of Proposals

6.1 The Submission Process

6.1.1 Submission Requirements. NASA utilizes an electronic process for management of the SBIR program. This management approach requires that a proposing firm have Internet access via the World Wide Web, and an e-mail address.

6.1.2 What Needs to Be Submitted. A proposal submission is comprised of two parts:

1. **Internet Submission.** The entire proposal including all forms must be submitted via the Internet. (http://sbir.nasa.gov)
2. **Postal Submission**. Postal submission includes an original signed proposal with all forms plus three copies.

> **Firms not able to obtain Internet access must request an exemption by calling 301-286-5661 or 301-937-0888 by Wednesday, June 30, 1999.**

6.2 Internet Submission

6.2.1 Electronic Technical Proposal Preparation. The term "Technical Proposal" refers to the part of the submission as described in Section 3.2.4.

Word Processor. NASA converts all technical proposal files to PDF format for evaluation purposes. Therefore, NASA requests that technical proposals be submitted in PDF format, and encourages companies to do so. Other acceptable formats for PC are AmiPro, ClarisWorks for Windows, MS Works, Text, MS Word, WordPerfect, Postscript, and Adobe Acrobat. For Macintosh, the acceptable formats are ClarisWorks, MS Works, MacWrite Pro, Text, MS Word, WordPerfect, Postscript, and Adobe Acrobat. Unix and TeX users please note that due to PDF difficulties with non-standard fonts, please output technical proposal files in DVI format.

Graphics. The offeror is encouraged for reasons of space conservation and simplicity, but not required, to embed graphics within the word processed document. For graphics submitted as separate files, the acceptable file formats (and their respective extensions) are: Bit-Mapped (.bmp), Graphics Interchange Format (.gif), JPEG (.jpg), PC Paintbrush (.pcx), WordPerfect Graphic (.wpg), and Tagged-Image Format (.tif).

Limitations. While only the paper copy will be screened for administrative compliance, the various files comprising the electronic version are required to exactly reflect the paper version.

Virus Check. The offeror is responsible for performing a virus check on each submitted technical proposal. As a standard part of entering the proposal into the processing system, NASA will scan each submitted electronic technical proposal for viruses. **The detection, by NASA, of a virus on any submitted electronic technical proposal, may cause rejection of the proposal.**

6.2.2 Electronic Handbook. An Electronic Handbook for submitting proposals via the internet is hosted on the NASA SBIR Homepage (http://sbir.nasa.gov). The handbook will electronically guide the firms through the various steps required for submitting a SBIR proposal and issue secure-user identification and passwords for each submission. Communication between NASA and the firm will be via a combination of electronic handbooks and e-mail.

> **Important:** After the offeror has submitted Forms 9A, 9B, and 9C via the Internet, the offeror may use the handbook to print the three forms locally. These forms should be signed as appropriate and included in the postal submission.

6.3 Postal Submission

Postal Submissions are comprised of:

1. One original signed paper copy of the proposal, including paper copies of all original forms (as stated in Section 6.2)
2. Three additional paper copies of the entire proposal. Each proposal copy is to be stapled separately.

6.3.1 Physical Packaging Requirements for Paper Copies of Proposal. Do not use bindings or special covers. Staple the pages of each copy of the proposal in the upper left-hand corner only. Secure packaging is mandatory. NASA cannot process proposals damaged in transit. All items for any proposal must be sent in the same envelope. If more than one proposal is being submitted, each proposal must be in its own envelope, but all proposals may be sent in the same package. Do not send duplicate packages of any proposal as "insurance" that at least one will be received.

> A checklist is included in this Solicitation to assist the offeror in submitting a complete proposal. The checklist should not be submitted with the proposal.

6.3.2 Where to Send Proposals. All proposals that are mailed through the U.S. Postal Service first class, registered, or certified mail; proposals sent by express mail or commercial delivery services; or hand-carried proposals **must be** delivered to the following address between 8:00 a.m. and 5:00 p.m. EDT:

NASA SBIR Support Office
REI Systems, Inc
4041 Powder Mill Road
Suite 311
Calverton, MD 20705-3106

The following telephone number may be used when required for reference by delivery services: 301-937-0888.

6.3.3 Deadline for Proposal Receipt. Deadline for receipt of Phase-I proposals is 5:00 p.m. EDT on Wednesday, July 14, 1999. Any proposal received after that date and time shall be considered late. Since the postmark (or other carrier’s date mark) will be the evidence on which the decision is made, offerors must assure themselves that the postmark (or other carrier’s date mark) is clear and easily legible; hand cancellation is suggested. Postage meter date stamps are not acceptable.

It is not sufficient for an electronically submitted proposal to be on time, the signed original paper version must be received at NASA by the date and time stated above. Proposals may not be submitted by facsimile. Late proposals will not be eligible for award and will be rejected without review.

6.4 Acknowledgment of Proposal Receipt

NASA will acknowledge receipt of proposals to the CEO’s e-mail address as provided on the proposal cover sheet. If a proposal acknowledgment is not received within 30 days following the closing date of this Solicitation, the offeror should call 301-937-0888.

6.5 Withdrawal of Proposals

Proposals may be withdrawn by written notice, signed by an officer of the company. Withdrawal notice must include proposal number and title.

7. Scientific and Technical Information Sources

7.1 NASA SBIR Homepage

Detailed information on NASA's SBIR Program is available at: **http://sbir.nasa.gov.**

7.2 NASA Commercial Technology Network

The NASA Commercial Technology Network (NCTN) contains a significant amount of on-line information about the NASA Commercial Technology Program. The address for the NCTN homepage is: **http://nctn.hq.nasa.gov/**

7.3 NASA Technology Utilization Services

The **National Technology Transfer Center (NTTC)**, sponsored by NASA in cooperation with other Federal agencies, serves as a national resource for technology transfer and commercialization. NTTC has a primary role to get Government research into the hands of U.S. businesses. Its gateway services make it easy to access databases and to contact experts in your area of research and development. For further information, call 800-678-6882.

NASA's network of **Regional Technology Transfer Centers (RTTCs)** provides business planning and development services. However, NASA does not accept responsibility for any services these centers may offer in the preparation of proposals. RTTCs can be contacted directly as listed below to determine what services are available and to discuss fees charged. Alternatively, to contact any RTTC call 800-472-6785.

Northeast:
Center for Technology Commercialization
Massachusetts Technology Park
1400 Computer Drive
Westboro, MA 01581-5054
Phone: 508-870-0042
URL: http://www.ctc.org

Southeast:
Southern Technology Applications Center
University of Florida, College of Engineering
1900 SW 34th Street, Suite 206
Gainesville, FL 32608-1260
Phone: 352-294-7822
URL: http://www.state.fl.us/stac

Mid-Continent:
Mid-Continent Technology Transfer Center
Texas Engineering Extension Service
Technology & Economic Development Division
College Station, TX 77843-8000
Phone: 409-854-2913
URL: http://teex.cy-net.net/MCTTC

Mid-Atlantic:
Mid-Atlantic Technology Applications Center
University of Pittsburgh
3400 Forbes Avenue, 5th Floor
Pittsburgh, PA 15260
Phone: 412-383-2500
URL: http://www.mtac.pitt.edu/WWW

Mid-West:
Great Lakes Industrial Technology Center
Battelle Memorial Institute
25000 Great Northern Corporate Center, Suite 450
Cleveland, OH 44070-5310
Phone: 440-734-0094
URL: http://www.battelle.org/glitec

Far-West:
Far-West Regional Technology Transfer Center
University of Southern California
3716 South Hope Street, Suite 200
Los Angeles, CA 90007-4344
Phone: 800-642-2872
URL: http://www.usc.edu/dept/engineering/TTC/NASA

7.4 Federal Research in Progress (FEDRIP) Database

On-line access to abstracts of research from all agencies is available through the FEDRIP database. FEDRIP is accessible through DIALOG, a private information service. For a free copy of the FEDRIP Search Guide, call 703-605-6000 and ask for order number PB96-153606.

7.5 United States Small Business Administration

The Policy Directives for the SBIR Program, which also state the SBA policy for this Solicitation, may be obtained from the following source. SBA information can also be obtained at: http://www.sbaonline.sba.gov/.

Office of Innovation, Research and Technology
U.S. Small Business Administration
409 Third Street, S.W.
Washington, D.C. 20416
Phone: 202-205-7701

7.6 National Technical Information Service

The **National Technical Information Service**, an agency of the Department of Commerce, is the Federal Government's central clearinghouse for publicly funded scientific and technical information. For information about their various services and fees, call or write:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Phone: 800-553-6847
URL: http://www.ntis.gov

8. Research Topics

Introduction

The SBIR Program Solicitation is aligned with the established NASA management structure of the Strategic Enterprises (http://www.nasa.gov).

The Enterprises identify, at the most fundamental level, what NASA does and for whom. Each Strategic Enterprise is analogous to a strategic business unit employed by private-sector companies to focus on and respond to their customers' needs. Each Strategic Enterprise has a unique set of goals, objectives, and strategies. Research topics and subtopics in this Solicitation are organized by the four NASA Strategic Enterprises:

Aero-Space Technology
Human Exploration and Development of Space
Earth Science
Space Science

In addition, synergy among the non- Aero-Space Technology Enterprises is captured in a separate section in the Solicitation called:

Thrust Areas

8.1 AERO-SPACE TECHNOLOGY

NASA's Aero-Space Technology Enterprise pioneers the identification, development, verification, transfer, application, and commercialization of high-payoff aeronautics technologies. It seeks to promote economic growth and security and to enhance U.S. competitiveness through safe, superior, and environmentally compatible U.S. civil and military aircraft and through a safe, efficient national aviation system. In addition, the Enterprise recognizes that the space transportation industry can benefit significantly from the transfer of aviation technologies and flight operations to launch vehicles, the goal being reducing the cost of access to space. The Enterprise will work closely with its aeronautics customers, including U.S. industry, the Department of Defense, and the Federal Aviation Administration, to ensure that its technology products and services add value, are timely, and have been developed to the level where the customer can confidently make decisions regarding the application of those technologies.

http://www.hq.nasa.gov/office/aero

01 Aviation Safety and Capacity

Aviation Safety represents the effective interaction and integration of five component technologies: 1) zero-tolerance for error in safety critical software and hardware, including software design and testing, power and propulsion development, propulsion control and integration; 2) design and implementation of an effective system to detect and restrict propagation of error and failure in system health monitoring and data analysis; 3) environmental impact on system performance, including effects of aging, stress, and icing and on information to human monitors/operators; 4) effective and safe design for control of multiple aircraft in the airspace system, through the integration of air and ground based air traffic systems; and 5) integration of human factors in all aspects of the aviation systems operation.

01.01 Human Factors in Aviation Operations
Lead Center: ARC
Participating Center(s): none

An important objective in aviation human factors research is to address the interaction of humans with engineered systems. As flight and Air Traffic Control crew roles evolve from those of systems operators to those of systems managers, innovative technologies (devices, techniques, tools, models, and procedures) are needed that pertain to the automation, environment, crew information processing, decision-making, and associated cognitive factors. Innovative and economically attractive approaches are sought to advance technologies supportive of both flight safety and improved efficiency in the following areas:

Reliable Operations
- Individual and crew performance factors.
- Distributed decision-making involving operators, controllers and dispatchers.
- Fatigue and circadian evaluation methods and countermeasures.
- Error reduction in aircraft maintenance.
- Methods of integrating air and ground roles and responsibilities under advanced Air Traffic Management (ATM) concepts.
- Technologies for training on advanced systems and for evaluation of training effectiveness.
- Human performance measurement technology suitable for use in and assessment of operational environments.
- Simulation and modeling tools to assess benefits of new concepts.

Information Management and Display
- Advanced display technologies.
- Integrated displays and procedures.
- Operational concepts and crew system interfaces.

Human-Automation Interaction
- Design methods for human-centered automation.
- Status monitoring systems that inform, advise, or aid the flight crew.
- Flight path planning, re-planning, and communication aids.

01.02 Advanced Concepts in Air-Traffic Management
Lead Center: ARC
Participating Center(s): none

Air-Traffic Management (ATM) combines the traditional separation assurance performed by Air-Traffic Control (ATC) and the flight-path management functions concerned with improving system capacity and capability. The challenge for the next generation ATM system is to accommodate growth in air traffic while reducing the aircraft accident rate by a factor of five within 10 years, and by a factor of ten within 20 years. This can only be achieved by the introduction of technical innovations in communication, navigation, and surveillance (CNS) and by the development of decision-support tools for controllers, pilots and airline operations. It also requires a new look at the way airspace is managed and automation of some crew functions, thereby intensifying the need for a careful integration of machine and human performance. Innovative and economically attractive approaches are sought to advance technologies in the following areas:

- Decision-support tools (DST) to assist pilots, controllers and dispatchers in all parts of the airspace (en route, terminal and surface).
- Integration of DST across different airspace. Simulation and modeling tools to assess benefits of new concepts. Technologies and concepts leading to greater airborne operational independence.
- Methods of integrating air and ground roles and responsibilities.
- Distributed decision-making and its impact on the stability of the airspace.
- System recovery and safety in the event of failure of sensors and decision-support tools.
- Weather modeling and improved trajectory estimation.
- New concepts in air space management.
- Role of data exchange and datalink in co-operative decision making.
- Impact of reusable launch vehicles (RLV) and other unmanned air vehicles on ATM.
- Human factors and workload concepts relating to safe control/integration of aircraft and other ground vehicles systems.
- Concepts and innovative methods to integrate simultaneous movement of the ground vehicles and the aircraft fleet.

01.03 Aircraft Ice Protection Systems
Lead Center: GRC
Participating Center(s): none

Improved protection against in flight aircraft icing remains an important objective in aviation safety. NASA seeks proposals that address ice protection, detection, remote sensing technologies, and environment measurement. Proposals are invited that offer improvements through innovative design concepts or integration of existing technologies. Of particular interest are technologies that are compatible with emerging technologies being utilized in new aircraft designs (i.e., sensitive electronic systems, advanced wing design). Onboard systems must be aerodynamically non-intrusive, practical, and must consider weight, power, and size for integration into aircraft.

This subtopic solicits innovative concepts that will lead to highly effective and efficient ice protection systems and techniques that are applicable to all classes of aircraft. To receive consideration for funding, all proposals submitted under this subtopic must demonstrate significant advancement over existing technologies. The areas of greatest interest are:

- Non-obtrusive and practical in-flight reactive ice detection that is sensitive to the full possible spectrum of temperatures, droplet sizes, and liquid water contents. Proposals must show a significant decrease in ice detection system end-user cost compared to current certified systems. An appropriate price goal of the final product is $2,000 per system; this price should include all costs associate with development, manufacture, and certification.
- Practical, in-flight and/or ground-based, real-time, remote sensing of the super-cooled water droplet and temperature environment. Technology must be capable of quantifying the environment to allow for the prediction of the severity of airframe icing, and to identify potential avoidance and escape routes, and must have practical range and cloud penetration capability.
- Lightweight, low power, and low cost de-icing and anti-icing systems, including technologies that protect composite structures. A system must have minimal aerodynamic impact in both the normal and icing environments and should be capable of operating automatically or with minimal pilot interaction.
- Integrated cloud physics measurement package that can identify liquid water content, droplet size, and outside air temperature in atmospheric icing conditions. The system will be mounted on non-icing research aircraft, must be compact in size and weight, and should consider remote location of the sensor processing to allow minimum intrusion into an aircraft skin. Options for either telemeter or onboard storage of data should be

examined. The sensors must be reliable, self-calibrating, and self-checking, and at least as accurate as the current cloud physics measurement devices.

01.04 High Integrity Systems and Algorithms
Lead Center: LaRC
Participating Center(s): GSFC

The simultaneously increasing complexity of flight systems, and demand for their safe and reliable operation motivate development of techniques for design of high-integrity avionics hardware and software. These include formal, system-level methods for design of hardware and software, providing verifiably safe and reliable execution of the avionics functions. They also include guidance, navigation, and control (GNC) and other vehicle management algorithms that contribute to flight integrity by detecting and identifying adverse conditions such as vehicle faults or erroneous controlled flight, then reconfiguring the vehicle's GNC laws to ameliorate these conditions. In particular, innovative approaches are sought in two main areas: (1) specification, design, and analysis methods for high-integrity digital systems, and (2) theory for synthesis and analysis of GNC algorithms and laws that preserve performance or degrade gracefully as the vehicle experiences breakdown of subsystems.

The system design methods of interest include the following:

- Mathematics-based methods for specification, design, and analysis of digital systems.
- Mathematics-based methods for analyzing the causes of failures in digital systems, especially failures leading to vehicle accidents.
- Techniques and tools for integrating formal methods with existing methods, tools, languages, and development standards (such as, RTCA/DO-178B).
- Metrics, measures, and experimental assessment of the effectiveness of particular software development techniques and processes.
- Software safety and risk assessment methods.
- Verified libraries for semi-automatic proof checkers.
- Executable specification languages with complete formal semantics.
- Formally defined specification and programming languages for developing time-critical applications and distributed and parallel software.
- Automatic program generators.
- Error detection and assessment methods, especially automated testing and verification techniques.
- Automated tools and environments to support managing and developing safety-critical systems.
- Innovative approaches to software and systems reuse.

The GNC algorithms of interest include theory and synthesis techniques for:

- Rapid reselection or recalculation of the vehicle's flight profile and/or GNC laws to accommodate sudden degradation of or change in its dynamics.
- Efficient and reliable algorithms for fault detection and identification (FDI) with emphasis on FDI of system-level faults which adversely affect the vehicle's dynamics.
- GNC laws that are robust or insensitive to system failures and/or FDI errors.

Approaches that integrate elements from both areas are especially sought.

01.05 Automated On-Line Health Management and Data Analysis
Lead Center: DFRC
Participating Center(s): none

Online health monitoring is a critical technology for improving transportation safety in the 21st century. Safe, affordable, and more efficient operation of aerospace vehicles requires advances in online health monitoring of vehicle subsystems and information monitoring from many sources over local/wide area networks. On-line health monitoring is a general concept involving signal-processing algorithms designed to support decisions related to safety, maintenance, or operating procedures. The concept of on-line emphasizes algorithms that minimize the time between data acquisition and decision-making.

This subtopic seeks solutions for on-line aircraft subsystem health monitoring. Solutions should exploit multiple computers communicating over standard networks where applicable. Solutions can be designed to monitor a specific subsystem or a number of systems simultaneously. Resulting commercial products might be implemented in a distributed decision-making environment such as a virtual flight research center, a disciplinary-specific collaborative laboratory, an onboard diagnostics system, or a maintenance and inspection network of potentially global proportion.

Proposers should discuss who the users of resulting products would be, e.g., research/test/development; manufacturing; maintenance depots; flight crew; airports; flight operations or mission control; air traffic management; or airlines. Proposers are encouraged to discuss data acquisition, processing, and presentation components in their proposal. Examples of desired solutions targeted by this subtopic include:

- Real-time autonomous sensor validity monitors.
- Flight control system or flight path diagnostics for predicting loss of control.
- Automated testing and diagnostics of mission-critical avionics.
- Structural fatigue, life cycle, static, or dynamic load monitors.
- Automated nondestructive evaluation for faulty structural components.
- Electrical system monitoring and fire prevention.
- Applications that exploit wireless communication technology to reduce costs.
- Model-reference or model-updating schemes based on measured data that operate autonomously.
- Proactive maintenance schedules for rocket or turbine engines, including engine life-cycle monitors.
- Predicting or detecting any equipment malfunction.
- Middleware or software toolkits to lower the cost of developing online health-monitoring applications.
- Innovative solutions for harvesting, managing, archival, and retrieval of aerospace vehicle health data.

01.06 Propulsion and Airframe Failure Data and Mitigation
Lead Center: GRC
Participating Center(s): LaRC

NASA is concerned with the prevention of hazardous and accident conditions and the mitigation of their effects when they do occur. One emphasis is on fire. The prevention, detection, and suppression of fires are critical goals of accident mitigation. Aircraft fires represent a small number of actual accidents, but the number of fatalities due to in-flight, post-crash and on-ground fires is large. Recent advances have made significant progress for cabin fire safety (e.g., fire-blocking layers in seat cushions); however, new areas of aircraft fire research have been identified (e.g., fuel tank flammability reduction).

A second emphasis is on crashworthiness. For all transport aircraft accidents, 45% of those, which involve serious injuries or fatalities, are survivable. Besides impact alone, survivability is often a function of the combined effects physical injury and the effects of subsequent fire and smoke. Technology is needed to further protect passengers from the effects of the crash or mitigate the aftereffects to allow the escape of passengers.

A third emphasis is on the problems that may result from mal-functions of aging equipment in the service of commercial transport aircraft, general aviation, and commercial rotorcraft. Because of the needs of increased competition and growth in passenger and cargo traffic, the service lives of dependable aircraft models are being extended. Current inspection and overhaul programs focus almost exclusively on structural integrity and the effects of structural corrosion and fatigue. However, much less attention is given to the potential effects of age on non-structural components, which include electrical wiring; connectors, wiring harnesses, and cables; fuel, hydraulic and pneumatic lines; and electro-mechanical systems such as pumps, sensors, and actuators. Deterioration of aircraft components, particularly wiring and electrical equipment, is also linked to breakdowns and unanticipated ignition sources that can cause fires in aircraft flight.

A final emphasis is on propulsion system health management in order to prevent or accommodate safety-significant malfunctions. Past advances in this area have helped improve the reliability and safety of aircraft propulsion systems. However, propulsion system component failures are still a contributing factor in numerous aircraft accidents and incidents. Advances in instrumentation, health monitoring algorithms, and fault accommodating logic are sought which help to further reduce the occurrence of and/or mitigate the effects of safety-significant propulsion system malfunctions.

Products and technologies are sought to enhance human survivability in the event of an accident, to assure continued airworthiness of the aging aircraft, and to monitor system health. Considerations should be made for affordability and retrofitability to the commercial transport, general aviation, and rotorcraft fleets. These include the following areas:

- Technology for fire prevention, detection, and suppression of potential in-flight fires in fuel tanks, insulation, cargo compartments, and other inaccessible locations.
- Technology to provide fuel tank flammability reduction.
- Technology to minimize fire hazards in crashes and to prevent or delay fires, for example, fuel modifications, fuel-system modifications to eliminate spills, and on-demand suppression while not presenting a weight or performance penalty.
- Design and injury criteria and dynamic analyses to enhance crash safety.
- Systems approach to crashworthy designs, which may include validated occupant/seat/structural interaction analyses.
- Energy-absorbing seat and structural concepts and materials.
- Technology for occupant protection in a crash, including advanced restraints and supplemental restraints.
- Concepts to extend the useful safe life of airframe structures and non-structural systems.
- Advanced NDE techniques that can be field demonstrated for aging engines.
- NDE-based material and structural modeling that can be integrated in life models for remaining life assessment of airframe and engine components.
- Concepts to prevent catastrophic failures of engine components, or to ensure fragment containment.
- Health management technologies such as advanced instrumentation, health monitoring algorithms, and fault accommodating logic, to predict, diagnose, and prevent safety significant propulsion system malfunctions.
- Low cost methods for failure prediction and testing of the above aircraft failure-prevention and mitigation technologies.
- Methods for integration of the above aircraft failure-prevention and mitigation technologies into existing or new aircraft.

01.07 Non-Destructive Evaluation and Health Monitoring of Materials and Structures
Lead Center: LaRC
Participating Center(s): GRC, MSFC

Innovative and commercially viable concepts are being solicited for the development of non-destructive evaluation (NDE) and health-monitoring sensors, instrumentation, and computational models for signal processing and data interpretation to establish quantitative characterization and event determination. Evaluation sciences include ultrasonics, laser ultrasonics, optics and fiber optics, shearography, video optics and metrology, thermography, electromagnetics, acoustic emission, x-ray and x-ray detectors, and related management of digital NDE data. NDE and health-monitoring technologies may be applied to characterizing material properties; assessing effects of defects in materials and structures; evaluating of mass-loss in materials; in-situ monitoring and control of materials processing; detecting cracks, porosity, foreign material, inclusions, corrosion, and disbonds in structures; detecting cracks under bolts; and real time and in-situ monitoring, reporting, and damage detection for structural durability and life prediction. Damage detection that includes cracks, delaminations, disbonds, degradation, buckling, and characterization of load environment on a variety of structural materials and geometries including thermal protection systems of ceramic and metallic tiles, “blankets,” and bonded configurations. Uses include identification of loads exceeding design, monitoring loads for fatigue and preventing overloads, suppression of acoustic loads, and early detection of damage. Thermal protection materials include aluminum, titanium, stainless steels, Inconel, graphite-epoxy and other composites, and structural configurations including honeycomb, plate, thick and thin laminates, and truss tubes. NDE and health-monitoring concepts would be applied to low density and high temperature material and component systems of interest to NASA, including superalloys and monolithic ceramics; polymeric, intermetallic, and ceramic matrix composites; polymers, light metallic alloys, metal matrix composites, metal laminates, inorganic glasses, carbon-carbon composites, refractory-matrix composites; material system blends, aluminum-lithium weldments, composite reinforcement architectures, adhesives, sealants, advanced bearings, and coatings. The anticipated structural applications to be considered for NDE and health monitoring development include a variety of high stress and hostile aero-thermo-chemical service environments projected for subsonic, supersonic and hypersonic aircraft structures, propulsion and power structural systems. There is additional specific interest in non-contacting, remote, rapid, and less geometry sensitive technologies that reduce acquisition costs or improve system sensitivity, stability, and operational costs.

02 Subsonic Transport Environmental Compatibility

NASA has very aggressive goals for ensuring the noise and emission environmental compatibility of future aircraft. They are to reduce the perceived noise levels of future aircraft by a factor of two (10 EPNdB) within ten years, and a factor of four (20 EPNdB) within 20 years and to reduce emissions of future aircraft by a factor of three within 10 years and a factor of five within 20 years. These goals are necessary to meet increasingly stringent local, national, and international noise and emission regulations while enhancing operating safety and productivity and increasing aviation system throughput. Noise prediction and reduction technologies are required in the areas of propulsion source noise, nacelle aeroacoustics, airframe noise, and noise minimal flight procedures for jet and propeller airplanes and rotorcraft. In addition, aircraft interior noise reduction technologies are required to improve passenger and crew comfort. Emissions reduction technologies are required for a number of aerosols and particulates including nitrogen oxides, sulfur oxides, carbon dioxide, and water vapor.

02.01 Aircraft Noise Prediction and Reduction
Lead Center: LaRC
Participating Center(s): none

Innovative noise reduction concepts, techniques, and methods are needed for the design and development of efficient, environmentally acceptable airplanes and rotorcraft. Improvements in aircraft noise prediction and control are needed for jet, propeller, rotor, fan, turbomachinery, and airframe noise sources for community residents, aircraft passengers and crew. Innovations in the following specific areas are solicited:

- Fundamental and applied computational fluid-dynamics techniques for aeroacoustic analysis, particularly for use early in the design process.
- Reduction concepts and prediction methods for jet noise of subsonic, supersonic, and hypersonic aircraft.
- Concepts for active and passive control of fan, turbomachinery, and jet noise in engine nacelles.
- Reduction concepts and prediction methods for rotorcraft and advanced propeller aerodynamic noise.
- Simulation and prediction of aeroacoustic noise sources including airframe noise and propulsion-airframe integration.
- Computational and analytical structural acoustics techniques for aircraft interior noise prediction, particularly for use early in the airframe design process.
- Concepts for active and passive interior noise control for aircraft.
- Prediction and control of high-frequency aeroacoustic loads on advanced aircraft structures and the resulting dynamic response.

02.02 Propulsion System Noise Prediction and Reduction
Lead Center: GRC
Participating Center(s): none

NASA's aggressive subsonic aircraft noise reduction goals will require revolutionary advances in propulsion technologies. Some of the key technologies needed to achieve these goals are fast, highly accurate computational acoustic methods, advanced source identification techniques, and revolutionary propulsion systems for reduced noise and low cost. Advanced computational methods are needed that can both model the relevant flow physics and be used in a design environment. Source identification techniques are needed for both wind tunnel model scale tests and full scale static engine tests to determine the locations of the disturbances that contribute to the overall engine noise levels. It is anticipated that revolutionary noise reduction concepts will be needed to achieve future subsonic noise reduction goals. Therefore, advanced noise reduction concepts need to be identified that provide economical alternatives to conventional propulsion systems. NASA is soliciting proposals in one or more of the following areas for Propulsion System Noise Prediction and Reduction:

- Innovative source identification techniques for turbomachinery noise. The technique shall be described and demonstrated on a relevant source. A simple source may be used where the solution is known to demonstrate the technique. A clear explanation of how the technique can be applied to turbofan engines should be included. The technique should be capable of identifying sources contributing to dominant engine components, such as fan and jet noise. Fan Noise: The technique shall be capable of separating fan sources such as fan-alone versus fan/stator interaction for both tones and broadband noise. Sufficient resolution is needed to determine the location of the dominant sources on the aerodynamic surfaces. Jet Noise: The technique shall be capable of locating both internal and external mixing noise for dual-flow nozzles found in modern turbofans.
- Innovative turbofan source reduction techniques. Methods shall emphasize noise reduction methods for fan, jet and core components without compromising performance for turbofan engines. A resulting engine system that incorporates one or more of the proposed methods should be capable of reducing perceived noise levels for subsonic engines anywhere from 10 to 20 EPNdB relative to FAR 36, Stage 3 certification levels.
- Highly accurate and efficient computational methods for the simulation of turbomachinery noise sources. Methods should have the potential of being 100 (or more) times faster than existing methods while accurately resolving acoustic disturbances.

02.03 Subsonic Aircraft Systems Emissions Reduction
Lead Center: GRC
Participating Center(s): none

Current environmental concerns with subsonic aircraft center around global warming and the impact on the Earth's climate and, if not addressed, may threaten future market growth. Carbon dioxide (CO_2) and oxides of nitrogen (NOx) are the major emittants of concern coming from commercial aircraft engines. CO_2 and NOx are both greenhouse gases, which impact the warming of the Earth's climate. Also, NOx can destroy ozone in the upper atmosphere, which protects humans from harmful UV radiation from the sun, and NOx can produce ozone in the lower atmosphere around airports, which appears as smog and causes breathing problems in humans. Current state-of-the-art engines and combustors in most subsonic aircraft are fuel efficient and meet the 1996 ICAO nitrogen oxide (NOx) limits. The Kyoto Agreement is applying pressure for additional CO_2 reductions, and Europe and the U.S. Environmental Protection Agency are applying pressure for additional NOx reductions at takeoff and possibly cruise conditions. Stringent CO_2 and NOx limits could result in emissions fees or limited access to some countries. Also, recent observations of aircraft exhaust contrails (from both subsonic and supersonic flights) have resulted in growing concern over aerosol, particulate, and sulfur levels in the fuel. In particular, aerosols and particulates from aircraft are suspected of producing high altitude clouds, which could adversely affect the Earth's climatology.

NASA has set some very aggressive goals for reducing emissions of future aircraft by a factor of three within ten years and by a factor of five within twenty years. Advanced concepts research for reducing CO_2 and analytical and experimental research in characterization (intrusive and non-intrusive) and control (through component design, controls, and/or fuel additives) of gaseous, liquid and particulates of aircraft exhaust emissions is sought. Specific subsonic aircraft operating conditions of interest include the landing-takeoff cycle as well as the in-flight portion of the mission.

Areas of particular interest include the following:

- New concepts for reducing carbon dioxide, oxides of nitrogen (NO, NO_2, NOy), unburned hydrocarbons; carbon monoxide, particulate, and aerosols emittants (novel propulsion concepts, injector designs to improve fuel mixing, catalysts, additives, etc.).
- New fuels for commercial aircraft which minimize carbon dioxide emissions.
- Innovative active control concepts for emission minimization with an integrated systems focus including emission modeling for control, sensing and actuation requirements, control logic development, and experimental validation are of interest.
- New instrumentation techniques are needed for the measurement of engine emissions such as NOy, SOx, HOx, atomic oxygen and hydrocarbons in combustion facilities and engines. Size, size distributions, reactivity, and constituents of aerosols and particulates are needed, as are temperature, pressure, density, and velocity measurements. Optical techniques that provide 2D and 3D data; time history measurements; and thin film, fiber optic, and MEMS-based sensors are of interest.

03 Space Transportation

Affordable access to space must be the ultimate goal in order for America to realize the potential for research and commerce in space. NASA envisions the space frontier as a busy crossroads of U.S.-led international science, research, commerce, and exploration. Our experience with this vast resource has already yielded new treasures of scientific knowledge, life-enhancing applications for use on Earth and fantastic celestial discoveries. The potential for the future seems almost limitless. Goals include reducing the payload cost to Low Earth Orbit by an order of magnitude, from $10K to $1K per pound, within 10 years and from $1K to $100's per pound by 2020.

03.01 Launch Vehicle Technologies
Lead Center: MSFC
Participating Center(s): none

Advanced launch vehicle systems will require high mass fraction, reliable system performance, and extended reusability in order to achieve cost goals. This subtopic emphasizes innovative hardware concepts, subsystems, and design and analysis tools to support development of launch vehicles (not including propulsion systems) while lowering operations cost. Methods, approaches, design and analysis tools, and hardware developed under this subtopic should address technical issues related to tanks, thermal protection systems, structures, guidance, navigation and control (GN&C), supporting discipline analysis, and system integration issues. Specific areas of interest for advanced technologies and innovations include the following:

- Low cost designs, concepts, and manufacturing processes for tanks and vehicle structures; and innovative approaches and techniques to reduce range costs of small launchers such as Bantam.
- Control and health management of vehicle structural systems by using sensors and effectors that have little influence on the structural system parameters with the exception of the structural damping parameters. Continuous estimation of center of mass and inertial properties. Real-time retuning of control algorithms to reflect known changes in vehicle response or sensor performance, and accurate, continuous estimation of fuel remaining onboard.
- Thermal-protection system concepts, instrumentation analysis tools, and testing techniques for reusable vehicles, cryo-tanks, and vehicle base regions.
- Innovative system level models that support the design and analysis of integration of vehicle subsystems and propulsion systems into the vehicle (such as the ability to assess operability of the systems and to model the impacts of design changes on vehicle cost, operations, vehicle aerodynamics, and controllability).

- Integrated CAD, solid-model, structural, dynamic, thermal, and fluid-flow analysis methods for multi-disciplinary analysis and optimization of launch vehicles, and vehicle subsystems; and improved vehicle analysis tools in the areas of stress, thermal, structural, and fluid dynamics.
- Automated propellant management systems; and technologies and innovative engineering capabilities to produce propulsion storage, feed, pressurization, fill and drain, vent, and support/restraint systems that are robust, lighter, or require less volume.
- Optimal fault detection and redundancy management strategies; onboard autonomous mission planning/abort mode determination; execution software and advanced navigation hardware/software architectures; and adaptive GN&C utilizing data from sensors such as the GPS.
- Analysis and testing techniques for prediction and measurement of damage and stress including life prediction and dynamic response in structures containing ceramic-matrix, metal-matrix composites, or other composite materials; and nondestructive evaluation of structural integrity of vehicle materials and subsystems. Methods for efficient characterization of frequency response functions of large structures, and analysis and testing techniques for passive and active vibration isolation devices for launch vehicles and payloads.

03.02 Revolutionary/Unconventional Propulsion Technologies
Lead Center: MSFC
Participating Center(s): GRC, JPL

This subtopic focuses on innovative, non-traditional propulsion technologies, devices and systems that could lead to dramatic reductions in launch costs, rapid and affordable travel among the planets, and missions beyond the solar system. Important aspects that should be addressed include analyses addressing feasibility and mission suitability, and plans for demonstrating concept feasibility via test/experiment. Areas of interest include:

- "Breakthrough" technologies based on "leading edge" physics research.
- Technology developments in antimatter production, storage, transportation, and utilization for application as a propulsion energy source.
- Propulsion applications of technology innovations in fission or fusion energy production.
- Technology innovations for offboard, beamed power-driven propulsion.
- Development of propulsion systems based on solar, laser or magnetically propelled sails or current loops.
- Components and subsystems for advanced airbreathing/rocket combined cycle engines, deeply cooled turbojets and liquid air cycle engine concepts.
- Advanced high-energy-density propellants and propellant storage/transfer techniques.

03.03 Space Transfer Technologies
Lead Center: MSFC
Participating Center(s): JSC

Advanced, innovative, technologies and system concepts that will achieve reductions in in-space transportation costs are sought. Technologies that offer significant mass or specific impulse improvements over current chemical systems are sought. Other technologies or system concepts that offer improved durability, reduced cost, and reusability over current systems are also of interest. Development of such systems and related technologies are sought to enable ambitious commercial, robotic, and human exploration missions in the future. Concepts that can be applied to high-payoff commercial applications are of particular interest. Proposals should emphasize the potential for reduction in cost, and improvements in performance, reliability, operability or manufacturability over existing systems. Areas of specific interest shall include:

- Chemical propulsion and fluid systems for engines that are used for orbit transfer, in-space transfer and ascent/descent missions are of interest. Other mission applications may include small chemical propulsion for reusable launch vehicles (in-space maneuvering and attitude control systems). Systems that use non-toxic (oxygen based) bipropellants are of primary interest, but advances in conventional hypergolic propellants are also sought. One type of propellant combination of specific interest for missions to the Moon, Mars, or other planetary bodies include those that can be made from indigenous materials. Figures of merit include lower weight, reduced cost, longer life, improved maintainability, and higher reliability. System/component technologies include: materials compatible with high-temperature, oxidizing and reactive environments; components for fluid isolation, pressure/mass flow regulation, relief quick disconnect, and flow control; techniques for metering, injection, and ignition of fluids in combustion devices; gaseous storage and pressurization systems; non-intrusive component and system diagnostics; systems for cryogenic fluid management, including liquid-free gas venting, gas free liquid propellant delivery, mass quantity gauging in reduced gravity environments, long term propellant storage (zero boiloff); and systems/components for actuation of aero-surfaces and valves using hydraulic, electro-hydraulic or electromechanical power drives.

- Enhancements to, or development of, new propulsion systems that use energy sources that do not have to be launched or extremely high density energy sources. These may be sources that are available in space such as solar interactions, electromagnetic fields, or atmospheres for capture. These also may utilize the release of binding energy or other high density energy generation methods. These sources may also use the exchange of momentum between two bodies. Technologies may be in the following areas:
  - Components or system level technologies for solar thermal propulsion. These may include: solar collectors or concentrators, lightweight concentrator support structure, engine/thruster for solar energy conversion, controls and pointing technologies, and system level technologies.
  - Electrodynamic tether propulsion systems or component level technologies. These may include: tether materials or coatings for improved performance and lifetime, designs and analysis for tether behavior and dynamics, testing and characterization techniques for tethers, and system level technologies.
  - Momentum transfer tether propulsion systems or component level technologies. These may include: tether materials or coatings for improved performance and lifetime, designs and analysis for tether behavior and dynamics, testing and characterization techniques for tethers, and system level technologies.
  - High power electric propulsion systems, including power supplies and thrusters.
  - Technologies for aerocapture or aeroassisted propulsion systems. These may include materials and thermal protection system technologies, modeling and analysis tools, and system integration issues.
  - Other propulsion systems that do not require chemical reactions to operate.

03.04 Lightweight Engine Components
Lead Center: MSFC
Participating Center(s): none

Next generation space propulsion systems must address the significant challenge of achieving lower life-cycle cost, increased performance, and higher reliability relative to current propulsion systems. Recent emphasis in the performance area has been placed on development of components having increased operational temperature capability, reduced weight, and reusability. Innovative designs and processing methodologies offer potential for cost reduction. NASA, through this subtopic, is seeking research proposals that emphasize justification for selection of matrix material constituents, fibers, interface coatings, fabric architecture, etc.; control of processing parameters to ensure successful scale-up and reproducibility; process verification with microscopic analysis (e.g., SEM, XRD, BET, etc.) and macroscopic analysis (e.g., tensile strength, interlaminar shear strength, thermal and physical properties, etc.); application specific verification by testing for permeability, thermal shock, etc.; and nondestructive evaluation of components and/or stock material. Composites are desired composed of fibers selected by the end users, high strength SiC fibers, carbon fibers, tungsten/rhenium/hafnium carbide type fibers, component health monitoring fibers, and a hybrid tow or architecture composed of the fibers mentioned. Matrices selected by end users, silicon, zirconium, and hafnium based matrices, and hafnium silicate and other high temperature –ate matrices are desired. Results in the development of high temperature engine components should quantifiably address the goals of the Access to Space initiative and describe the technology advancement payoff. Phase-I and Phase-II plans should include delivery of components, test data, and analyses as appropriate. Hoop or flat specimen tensile stress-strain curves and interlaminar shear data must be delivered in both Phase-I and Phase-II. Deliverables must also include representative tested and as-fabricated samples. A test matrix or matrices, detailing processing variables adjusted and the conditions the samples were tested under, must be delivered no later than one month after award date. As the program progresses, updated matrices must be delivered accordingly.

Specific areas of interest include, but are not limited to, the following:

- Development of lightweight turbomachinery components [e.g., integrally bladed disks (blisks), rotors, stators, housings, seals, etc.] having capability to operate in hot (> 1000 degrees C) hydrogen rich steam and oxygen rich environments.
- Development of fabrication techniques capable of producing uniform densities in CMC blisks for thicknesses ranging from one to three inches, and diameters up to eighteen inches.
- Innovative technologies providing lower cost, lightweight combustion components (e.g., cooled and uncooled thrust chambers and nozzles, injector faceplates, minimal erosion throats, etc.) for LOX/H2 and LOX/RP environments.
- Ultrahigh temperature (greater than 2000 degrees Celsius) propulsion and plasma confinement development for solar thermal absorbers and nuclear thermal applications.
- Development of functionally gradient materials for preceding applications.
- Low cost (with metrics), rapid, repeatable CMC fabrication development for preceding applications.
- Development of high temperature (greater than 300 degrees Celsius) polymer matrix composites for housings, lines and ducts, etc.
- Design and fabrication of inducers with a suction performance capability greater than 85,000 suction specific speed with inducer tip flow coefficient greater than 0.10.

All monolithic ceramic development must be justified for use on manned or unmanned flight vehicles. A commitment must be obtained from end-users that the risk and results of impact damage to the component is acceptable for any monolithic ceramic components.

03.05 Rocket Engine Test Operations
Lead Center: SSC
Participating Center(s): none

Proposals are solicited for innovative concepts in the area of propulsion test operations. Proposals should support the reduction of overall propulsion test operations costs (recurring costs) and/or increase reliability and performance of propulsion ground test facilities and operations methodologies. Specific areas of interest in this subtopic include the following:

Facility and Test Article Health Monitoring Technologies
- New innovative non-intrusive sensors for measuring flow rate, temperature, pressure, rocket engine plume constituents, effluent gas detection, hydrogen leak detection, and hydrogen fires.
- On-line particulate and quality sampling for facility propellant (liquid oxygen and hydrogen) and support gas systems (helium, hydrogen, oxygen, nitrogen, and missile-grade air).

Improvement in Ground-Test Operation, Safety, Cost-Effectiveness, and Reliability
- Smart system components (control valves, regulators, and relief valves) which provide real-time closed-loop control, component configuration, automated operation, and component health.
- Cryogenic propellant transfer system operation technologies which include automated propellant transfer, automated propellant-line (liquid hydrogen) purge systems, and automated and/or manual propellant-line quick-disconnect systems.
- Long-life, liquid-oxygen-compatible seal technology.
- Cryogenic storage tank lifetime monitor systems for temperature cycles, stress, acoustics, pressure and shock.

Application of System Science to Ground-Test Operations in a Resource Constrained Environment
- Digital simulation techniques to support decision making processes to address reliability, availability, and return on investment and training of environment for test conductors.
- Techniques to improve high-speed data acquisition and high-speed video systems for test area data and video transmissions.
- Techniques to reduce required sample size to maintain acceptable levels of confidence in cost data.
- Risk management techniques.

03.06 Materials, Material Processing, and Coatings for Launch Vehicle and Spacecraft Components
Lead Center: MSFC
Participating Center(s): none

The purpose of this subtopic is to promote development in the areas of low-density materials, materials processing and coatings technologies that will provide safe, reliable, lightweight, and less expensive launch vehicle and spacecraft components. This subtopic emphasizes the development of advanced materials and fabrication processes for advanced reusable vehicle systems. Materials and/or fabrication processes developments should focus on reducing the weight of systems and components while maintaining reliability and long service life at or above current capabilities.

Enhancements in the following areas are of interest:

- Innovative fabrication technology that combines advanced composite materials and processing techniques; non-autoclave curing and alternate curing techniques, e.g., x-ray or electron beam, UV.
- Intelligent synthesis environment and collaborative engineering tools for manufacturing.
- Rapid, multidimensional preformed fabrication for continuous fiber-reinforced composites with simple or complex geometry and/or large dimensions.
- Manufacturing processes for liquid hydrogen and liquid oxygen compatible and reusable composite lines, ducts, and cryotanks.
- Production of lightweight tooling and mandrels for composite structures.
- Processing techniques for non-uniform composite structures.
- Damage-resistant composite structures (residual strength property measurement and prediction after impact).
- Advanced materials and processes for both oxygen-rich and high-temperature applications.
- Improved structural integrity materials for use in end-item component processing with rapid-prototyping technologies.
- Process control instrumentation for characterization and verification of material properties, including thermal, optical, electrical, mechanical and moisture absorption and composition utilizing new and innovative state-of-the-art technologies.
- Coatings technologies vital in developing advanced high-temperature superalloy-, intermetallic-, and ceramic-matrix composites with enhanced structural, environmental, and use-temperature capability.
- On-orbit repair for coating, bonding, seals, and structures.
- Adhesive bonding materials with high-performance capabilities in extreme environments such as cryogenic temperatures and elevated temperatures above 520 K.
- Surface preparation techniques for substrates such as aluminum, steels, titanium, epoxy and graphite composites, glasses, and ceramics.
- Paints and other surface coatings for space flight applications that are adherent to standard substrates and are free of flaking, low outgassing, stable alpha and epsilon, stable electrical behavior, and resistant to ionizing radiation and atomic oxygen.
- Optical cements with a stable refractive index resistant to ionizing radiation and low outgassing.
- Atomic oxygen resistant flexible coatings for materials such as thermal blankets and flexible composite structures.
- Innovative thermal spray or cold spray coating processes; or novel uses of existing thermal spray processes that substantially improve material properties, combine dissimilar materials in new and useful ways; or drastically increase efficiency, equipment life; or allow new applications previously limited by the current state of the art.

Thermal spray applications of interest include, but are not limited to:

- Dense deposits of refractory metals, ceramics, and metal carbides. Thickness greater than 0.125 inch is of particular interest.
- Application of thermally sprayed coatings to non-metallic and composite materials to enhance or extend utility or service limitations.
- Coatings for protection of materials to be used in gaseous oxygen-rich environments.

- Coating or spraying processes which allow forming of dense, high quality metallic or ceramic structural parts of complex geometry.
- Improvements in thermal spray hardware that improves operational life of frequently replaced components, particularly for plasma spray hardware.
- Thermal spray processes, hardware, or materials that allow application of high melting point materials to heat-sensitive substrate materials.
- Thermal spray or liquid metal forming without the use of a vacuum chamber.
- Innovative methods of corrosion protection which will reduce coating application time, increase coating life, eliminate steps in the coating application process and, in general, extend hardware life while reducing refurbishment costs. Alternative protection systems must be environmentally friendly, cost effective, durable enough to withstand launch environments and more effective than current methods of corrosion protection.

03.07 Bonding and Joining Technologies
Lead Center: MSFC
Participating Center(s): none

NASA seeks innovative technologies for bonding and joining of materials to improve the performance and affordability of future aerospace systems. Advancements are sought that improve joint efficiency, allow joining of a wider range of materials, improve the quality and cost-effectiveness of the joint, and extend the understanding of factors influencing these characteristics.

- Technologies and processes are sought for joining of aluminum alloys, especially in the application of cryotankage and structures for future space vehicles. Of particular interest are those applicable to high-performance aluminum-lithium alloys and aluminum metal-matrix composites. Additionally, methods for low cost fabrication in the more common aluminum alloys and other structural metallic alloys are of interest.
- Technologies are needed to improve control of welding, brazing and other joining processes as they are applied to joints for aerospace vehicles. These technologies should be compatible with the quality requirements for aerospace vehicles, and should include process control technologies as well as non-destructive examination methods.
- Techniques are needed for in-space welding and its associated operations, including welding, brazing, cutting, joint preparation, and non-destructive examination. These techniques would be applied to aluminum, stainless, and titanium alloys in plate and tube forms.
- Techniques and processes are sought for the joining of dissimilar refractory metals and ceramics capable of withstanding repeated cycling to or long-term sustained operation at very high temperatures (approaching the melting points of the materials being joined). Materials of interest include, but are not limited to, refractory metals such as TZM and titanium, ceramics such as mullite, alumina or silicon nitride, various carbon-carbon composites, graphite and CVD diamond. The requirement for sustained operation at high temperature severely restricts the use of active metal braze techniques, while the requirement for repeated high temperature cycling makes it essential that detailed consideration be given in the proposal to problems of CTE mismatch. Material properties of particular interest in the bonded assemblages include the electrical conductivity of the joint and its stability in both oxidizing and reducing atmospheres at high temperature. Prospective uses for the techniques developed under this subtask include the construction of ultracompact, highly-efficient furnaces and evaporators to enable particle experiments on the Space Shuttle and Space Station; bonding leading-edge components in supersonic aircraft such as the National Aerospace Plane; and fabrication of structural components for use on space missions close to the Sun such as Solar Probe. These techniques should have broad application in the commercial arena where the use of advanced ceramics and composites has been severely hindered by the inability to join such materials into components capable of withstanding the same harsh environments as the materials themselves.

04 General Aviation Revitalization

Numerous factors combine to create opportunities for revitalization of the U.S. general aviation industry and the role of a small aircraft transportation system for business and personal travel in the 21st century. These include rapid growth in air travel (increasing pressure on National Airspace System (NAS) capacity and safety and for affordable NAS operations for the Government and users), declining numbers of communities served by scheduled air carriers, increasingly stringent international environmental standards, an aging fleet of small aircraft, and aggressive foreign competition. NASA seeks innovative technologies supporting advances in flight systems, airspace and ground systems infrastructure, integrated design and manufacturing and aircraft configuration design concepts as well as general aviation propulsion technologies.

04.01 General Aviation Transportation System Technologies
Lead Center: LaRC
Participating Center(s): none

NASA seeks innovative technologies to support advances for small aircraft transportation systems that substantially increase the demand for retrofit of existing aircraft, new aircraft and airport and airspace utilization. Of specific interest are advanced, affordable, certifiable technologies for human-factors engineered display of flight information for total situational awareness and simplified integration of flight controls with displays, and propulsion systems. In addition, improvements are desired in cost-effective, user-friendly improvements in the graphical display of weather, traffic, and NAS facilities' information services in the cockpit. NASA also seeks innovations in manufacturing methods and materials. Specifically, proposals are sought for the following areas:

Aircraft Configuration

- Advanced concepts for roadable aircraft are desired. This category must include a sound business plan for production with a technical plan providing for compatibility with the emerging National Airspace System architecture and a certification plan to meet at least one of the following applicable FARs: Part 103 (Ultra-lite vehicle), Part 21.24 (Primary Category Aircraft), Part 23 (Certified Aircraft) or Part 27 (Rotorcraft), or Part 21.191 Advisory Circular AC No: 20-27 series (Experimental Homebuilt Aircraft).

Flight System Technologies, Information Systems and Pilot Vehicle Interface

- Cost-effective advances in emerging navigation and graphical weather displays, graphical depiction methods, intuitive cockpit display systems with emphasis on pilot-display interface, flight controls, voice interface, portable and wearable display technologies, communications and human factors engineering technologies to aid pilot decision-making and to reduce cockpit workload.

Certifiable Of-the-Shelf System Hardware and Software

- Affordable cockpit systems including sensors, attitude-heading reference systems, terrain, obstacle, and hazardous weather avoidance systems, and applications for standardized data bus system architectures such as firmware, software, design and maintenance tools, and flight information and management products for airplane systems status and flight planning.

Integrated Design and Manufacturing

- Innovative manufacturing methods and materials providing significant advances in the cost, safety, weight, and cabin comfort for general aviation aircraft through materials technology, structural designs and assembly, and crash-worthiness.

All proposals should include supportability plans (support infrastructure, maintenance requirements, operations, and training), certification plans (cite specific FARs), compatibility with current and future airspace architecture, and a clear path to commercialization.

04.02 Light Aircraft Engine Design, Systems, and Components
Lead Center: GRC
Participating Center(s): none

NASA seeks proposals that offer dramatic improvements in acquisition and life-cycle costs, performance, safety and reliability, environmental compatibility (noise, emissions and fuel), ease of operation and passenger comfort through innovative propulsion concepts and/or integration of innovative propulsion technologies. In all cases, the offeror must demonstrate acquisition and life-cycle costs that are at least comparable to current propulsion system costs. Anticipated benefits must be defined using appropriate theoretical and experimental data. An understanding of the basis of the technology innovation and its application to aircraft engines must be demonstrated. Offerors must address commercialization potential. Paths to FAA certification must be described. Proposals are sought in the following areas:

Propulsion System and Component Technologies
NASA seeks engine concepts (piston, turbine, unconventional) and engine component technologies for light aircraft that will result in substantial improvements over current piston engines. Any improvements in areas such as performance, safety, and environmental compatibility must be accomplished with affordability as a prime consideration. Substantially reduced costs, at least 50% less than current systems, are highly preferred.

Engine Control and Health Monitoring Technology
NASA seeks proposals for low cost electronic engine control and health monitoring systems which substantially reduce pilot workload, fuel consumption, and engine emissions, and increase time between overhaul (TBO) and safety. Engine diagnostics should focus on pilot notification of engine status and operability, post-flight diagnostic methods, trend analysis, and maintenance aides. Much of this technology already exists, but it is too costly and/or too costly to certify for light aircraft. In some cases, cost reductions by orders of magnitude must be achieved. Development of methods for using commercially available high volume hardware and achieving low cost software production and validation is encouraged.

05 Next Generation Aircraft Systems Design and Analyses Tools

The Aero-Space Technology Enterprise is engaged in developing the tools, techniques, and technologies to revolutionize the design and development processes of the aerospace industry with the goal to reduce the aerospace vehicle development cycle time by one-half. The concept of design spans the evaluation of requirements; consideration of manufacturing, operations support, and other non-traditional domains; effective utilization of ground and flight test results, up to the point of actual manufacture. Information technology, advanced physics-based analytical tools, methods to control the process of design, and innovative test instrumentation are key areas in this effort.

05.01 Rotorcraft/STOVL Aerodynamics and Dynamics
Lead Center: ARC
Participating Center(s): none

Many aspects of rotorcraft/STOVL (Short Take-Off and Vertical Landing) aerodynamics and dynamics are not thoroughly understood or adequately predicted to enable efficient and accurate design processes for economically viable, civil aviation aircraft with vertical lift/STOVL capability. NASA requires innovative methods, approaches, and technologies that describe phenomena involved in rotorcraft/STOVL aerodynamics, dynamics and acoustics; provide greater knowledge of the detailed characteristics of these phenomena; and permit well-verified designs. Innovative developments with applications to tilt rotors, single main rotor and tandem helicopters, co-axial helicopters, and rotors with circulation control are needed to refine next generation rotorcraft and STOVL aircraft that will meet civilian global aviation requirements for safer, quieter, more efficient, lower DOC aircraft. These requirements directly impact the enabling technology goals identified by NASA to support the agency's mission in rotorcraft.

Examples of problems currently of importance include: efficient rotor design processes which reduce design cycle time; improved vehicle performance with reduction in ownership and operation costs; advanced active control strategies/methodologies for aeromechanics control and enhanced vehicle capability; innovative solutions for reducing airframe vibration, rotor vibratory loads, and radiated noise; and improving rotorcraft safety. New analysis methodologies addressing the unique aspects of civilian rotorcraft/STOVL aircraft through CFD/CSM/CAA for individual and integrated vehicle systems are also sought.

05.02 Measurement, Modeling, Prediction, and Control of Complex Flows Over Aerospace Vehicles
Lead Center: LaRC
Participating Center(s): ARC, GRC

Subtopic addresses viscous flow prediction, modeling and control across the entire spectrum of aerodynamic and aerothermodynamic phenomena that may be encountered by subsonic-to-supersonic aircraft and aerospace vehicles. Critical to the ability to predict, model, and control the complex flows over these aircraft and aerospace vehicles are the detail data necessary to develop the understanding of the physical flow phenomena associated with these complex flows. Also high quality, definitive data are essential in validating flow models and prediction methodologies, as well as, assessing design and performance of flow control concepts and technologies. Therefore, innovations and ideas are solicited for advanced measurement systems and ground testing techniques with global measuring capabilities, higher bandwidth, and improved resolution. Additionally, the subtopic is interested in innovative ideas for and applications of computational and experimental techniques that will account for the complex aerothermodynamic, mixing, and combustion phenomena impacting the design and development of future space transportation vehicles, aero-assist orbital transfer vehicles, planetary entry probes, and hypersonic airbreathing propulsion systems. Phenomena of interest include, but are not limited to, boundary layer transition and turbulence; vortical and separated flows; equilibrium and finite-rate chemistry; thermodynamic and transport properties of multicomponent mixtures, gaseous radiation, gas-surface interactions, mixing and combustion, shock-wave/boundary-layer interactions; and laminar, transitional, and turbulent reacting flows.

Specific fluid mechanic and aerodynamic areas of interest include:

- Flow-physics modeling and control of transition and/or transitional flows, turbulence, and turbulence-related phenomena such as heat transfer, skin-friction, acoustics, mixing and combustion.
- Control and/or mitigation of complex flow phenomena such as separation, and vortical flows, including drag-due-to-lift, and shock wave drag.
- Numerical methods for solving fluid-flow equations that increase computational efficiency, accuracy, speed, and utility, including construction of new algorithms, improved computer languages, improved boundary condition procedures, efficient grid-algorithm interfacing, and applications of automation techniques. Additional considerations are grid-generation procedures, unstructured grids, solution-adaptive procedures, and grid quality measures.
- Analytical and numerical techniques that enhance the understanding of transition and turbulence phenomena and provide improved models to solve the Navier-Stokes equations.
- Scientists' workbenches with integrated, graphical tools for interactive geometry definition, grid-generation, flow visualization, and solution validation. Innovative scientific visualization includes techniques to identify and visualize the details of complex flow fields around 3-D aircraft.

Specific aerothermodynamic and hypersonic airbreathing propulsion areas of interest include:

- Innovative concepts for hypersonic vehicles and airbreathing propulsion systems with potential for improved performance and reduced structural weight fraction.
- Numerical methods with enhanced accuracy and efficiency for solving fluid-flow equations for hypersonic vehicles and airbreathing propulsion systems.
- Advanced test techniques and flow diagnostics (including non-intrusive flow diagnostics and surface diagnostics) for developing definitive databases in hypersonic facilities including shock-expansion pulse facilities.

- Global measurement techniques for pressure and heat transfer in high Mach number flows.
- Model fabrication techniques with reduced cost and construction time.
- Analysis, design, and optimization techniques and graphical user interfaces for hypersonic vehicles and airbreathing propulsion systems.

Specific measurement technology areas of interest include:

- Innovative molecular sensors for environmental and combustion measurements.
- A miniature integrated system of MEMS sensors and interface electronics for flow measurements including flow velocity, pressure, temperature, shear stress, vibration, force, attitude, and/or acceleration.
- A small onboard multichannel intelligent data system and/or a high-speed wireless (optical or radio frequency) data transfer system with 50 mega-bits-per-second or higher data rate for wind tunnel model applications.
- Optical flow diagnostic technologies capable of resolving velocity, density, temperature, etc., in a global sense to provide planar or volumetric data, or at multiple points within the flow to provide temporally dependent cross correlations at sample rates of 100 kHz.
- Systems for rapid fabrication of wind tunnel test models including advanced metallic and composite fabrication techniques, and integrated fabrication of instrumentation.
- Model attitude and deformation measurement system providing 0.005-degree accuracy in a highly dynamic vibratory environment.

05.03 Modeling and Simulation of Aerospace Vehicles
Lead Center: DFRC
Participating Center(s): none

Safer and more efficient design of advanced aerospace vehicles requires advancement in current predictive design tools. The goal of this subtopic is to develop more efficient software tools for predicting and understanding the response of an airframe under the simultaneous influence of aerodynamics and the control system, in addition to pilot commands. The benefit of this effort will ultimately be increased flight safety (particularly during flight tests), more efficient aerospace vehicles, and an increased understanding of the complex interactions between the vehicle subsystems. This subtopic solicits proposals for novel, multi-disciplinary, linear or nonlinear, dynamic systems simulation techniques. Proposals should address one or more of the objectives listed below:

- Prediction of steady and unsteady pressure and thermal load distributions on the aerospace surfaces, or similar distributions due to propulsive forces, by employing accurate finite element CFD techniques.
- Effective finite element numerical algorithms for multidisciplinary systems response analysis with adaptive three-dimensional grid/mesh generation at selected time steps.
- Effective use of high-performance computing machines, including parallel processors, for integrated systems analysis or pilot-in-the-loop simulators.
- Innovative applications of high-performance computer graphics or virtual reality systems for visualizing the computer model or results.
- Correlation of predictive analyses with test data or model update schemes based on measured information.

05.04 Revolutionary Vehicle Systems, Components, and Technologies
Lead Center: LaRC
Participating Center(s): none

NASA seeks highly innovative concepts for aircraft, airframe components, technologies and design methodologies for advanced aerospace vehicles for both military and civil applications. The emphasis in this subtopic is on new aircraft concepts and high-risk airframe technology areas that can revolutionize air travel, reduce environmental impact, ensure U.S. pre-eminence, and create new markets for U.S. civil and military aeronautics industries. The scope includes advanced aircraft concepts and airframe systems and components such as wing, fuselage, propulsion/airframe integration, control systems, avionics, and technologies applicable to these components. Specific technical areas of interest include the following:

- Advanced aircraft concepts and configurations of subsonic to hypersonic airbreathing vehicles and unique propulsion/airframe integration concepts which offer revolutionary increases in performance over conventional aircraft designs.
- Advanced technologies that reduce accidents caused by crew-induced errors, structural failures due to aging aircraft, and aircraft systems failures due to digital upset.
- Advanced airframe technologies that reduce the impact of aircraft on the environment in terms of emissions (by reducing fuel burn) and noise reduction.
- Advanced airframe technologies that reduce aircraft weight, enable balanced performance and significantly reduced vehicle cost and operation through development of innovative materials and low cost airframe structure fabrication techniques.
- Innovative system-oriented research to support, develop, and/or enable advanced airframe technologies and concepts that could impact the design and optimization of any future class of aircraft.
- Breakthrough technologies that deliver revolutionary increases in aerodynamic performance (supersonic, transonic, and subsonic cruise and low speed, high lift) and aerodynamic control.
- Efficient, design-oriented application software embodying the mathematical and algorithmic aspects of both multidisciplinary design optimization (MDO) and systems analysis methods for aerospace vehicles.
- Innovative human-centered designed, flight deck systems information technologies, such as for synthetic vision or weather, that provide appropriate crew situation awareness and successful vehicle mission management.

05.05 Intelligent Design Methods for Aerospace Vehicles
Lead Center: ARC
Participating Center(s): LaRC

America's aerospace community needs revolutionary new system design tools to meet the demands of the 21st century. These demands stem from ever increasing product complexity, coupled with a lack of knowledge early in the design process resulting from the radical nature of the configurations envisioned. In addition, enormous pressure exists to reduce design cycle time and cost, and integrate the efforts of design teams distributed around the world.

Fortunately, emerging information technology, integrated with traditional aerospace vehicle design technologies, can enable the development of such revolutionary systems. NASA intends to lead the charge in developing the next generation of design tools that will decrease current design cycle time and cost by 50%. These tools will seamlessly interconnect the design, simulation, operation, training, and maintenance phases of product development and will enable the operation of fully integrated, multidisciplinary, geographically distributed product teams. Specific technology areas include the following:

- Computational models using algorithmic and novel reasoning technologies as well as neural networks, fuzzy logic and genetic algorithms to allow improvements in the cost, speed, and robustness of high-fidelity physics-based analysis and design processes.
- Intelligent agents to include cost discriminators from large amounts of parametric systems and mission data.
- Interactive graphic-based tools, machine-independent human/machine interfaces, and web-based technologies, to facilitate integration of disciplinary software in analysis and design processes, and, to direct, redirect and monitor process execution.
- Algorithmic and reasoning technologies to allow for collaborative environments including remote execution on geographically distributed and heterogeneous computer systems.
- Frameworks to support establishment of collaborative and geographically distributed design environments capable of optimally handling complex aerospace vehicle analysis and design processes.
- Technologies, systems, interface standards and data protocols, possibly using Artificial Intelligence and fuzzy-reasoning agents, for storage, query and display of variable fidelity, multi-source, multi-dimensional and multi-discipline design data sets, to ultimately maximize the potential for human direction of the aerospace vehicle analysis and design process, and human understanding of the product designed.

- Dynamic, "on-the-fly" visualization of multi-parameter design spaces with the ability to interactively view the effects of individual parameters.
- Instrumentation and test techniques that provide high-fidelity global surface or global field design data, and knowledge-based processes and tools to reduce testing and enable flexible product operation.
- Common parameterized geometry and discretization tools (e.g., computational grid generators), including the related sensitivity analysis capabilities, for all the disciplines required in aerospace vehicle analysis and design to permit consistent product geometry representation.

05.06 Revolutionary Propulsion, Propulsion Systems and Components
Lead Center: GRC
Participating Center(s): none

NASA seeks highly innovative concepts for propulsion, propulsion systems, and components for advanced aerospace vehicles including subsonic, supersonic, and hypersonic flight. The emphasis in this subtopic is high-risk technology areas that can revolutionize air travel and create new markets for U.S. industry. Propulsion system components include inlets, propellers, fans, compressors, combustors, turbines, nozzles, fuels, and recouperator and/or regenerators. Specific technical areas of interest include the following:

- Advanced cooling concepts that provide reduced coolant penalties. This can include innovative cooling systems, materials concepts, fuel cooling of the combustor, and endothermic fuels and/or fuel additives to increase the heat-sink capacity or cooling capacity of the fuels.
- Development of new fuels for air-breathing vehicles in the speed range of Mach 0 (takeoff) to 25 that provide higher propellant density, net improvement in thrust efficiency, or thrust augmentation. Proposals should address analytic assessments of feasibility, practical demonstrations of fuel additive techniques using minimal/efficient/smart delivery systems, and/or demonstrations of thrust augmentation in nozzle test flows.
- Innovative concepts relating to the combustion process, including techniques to identify the onset of combustion instability in lean-burn and/or rich-burn, low-NOx combustors, designs to avoid instabilities, and active and passive combustion controls.
- Greater cycle efficiency with an emphasis on thermodynamic cycles including combined cycles. Specific examples include topping cycles, cycles which employ recouperators, and inlet flow conditioning which allows turbomachinery to operate at high speed flight conditions.
- Micro air-breathing propulsion systems and their integration into airframes, such as propulsion system integration into the skin of the wing or totally within the wing.
- Innovative concepts relating to injectors, mixing, and sprays for increased efficiency and performance, and reduced emissions. This also includes injection of gelled fuels into airbreathing engines.
- New engine concepts that allow advanced ceramic/composite materials to be utilized in the turbomachinery components. Specific examples include concepts to drive the turbomachinery from what is traditionally considered the tip region (i.e., exoskeletal engine), such that predominant forces in the blade are compressive. Enabling technologies for such systems are also of interest.

06 Experimental Flight Research

Experimental flight research is invaluable for exploring new concepts and for complementing and strengthening laboratory research. The subjects covered under this topic area are focused on (1) bringing innovative technology into flight research to explore new aerodynamic and airbreathing/rocket propulsion concepts, and (2) radically improving the overall effectiveness of the flight research process. Aerodynamic areas of interest range from concepts applicable to hypersonic orbit insertion to low Reynolds number high-altitude long duration atmospheric sampling applications. Propulsion areas of interest include entire system concepts that may incorporate combined propulsion cycles as well as innovative technology addressing system elements, such as high density fuel, engine system components, or regenerative power systems.

06.01 Very High Altitude Aircraft Technology
Lead Center: DFRC
Participating Center(s): none

NASA foresees the need for increased sustained subsonic flight capability above 65,000 feet altitude. The physical properties of the atmosphere change quickly at altitudes above 80,000 feet, and atmospheric flight at such extreme altitudes poses significant challenges in several aerospace technology areas. This subtopic solicits innovative proposals that advance technologies for the development and operation of aircraft, manned or unmanned, flying at subsonic speeds between 65,000 and 110,000 feet altitude.

Proposed technology developments should identify benefits to improved flight operations, increased endurance, range, and/or payload.

Specific areas of interest include:

- High power density, regenerative power sources.
- Collision avoidance systems for unpiloted or autonomous operations.
- High altitude subsonic aerodynamics, propulsion, structures and materials.
- Over-the-horizon command and control systems.
- Autonomous command and control.

Proposals for studies involving the development of specific design configurations are not of interest unless the contractor is proposing the feasibility of innovative concepts that have not been previously reported in the open literature.

06.02 Flight Sensors, Sensor Arrays and Airborne Instrumentation
Lead Center: DFRC
Participating Center(s): GRC, LaRC

Real-time measurement techniques are needed to acquire aerodynamic, structural and propulsion system performance characteristics in flight and to safely expand the flight envelope of aerospace vehicles. The scope of this subtopic is the development of sensors, sensor systems, sensor arrays or instrumentation systems for improving the state-of-the art in aircraft ground or flight testing. This includes the development of sensors to enhance aircraft safety by determining atmospheric conditions. The goals are to improve the effectiveness of flight testing by: simplifying and minimizing sensor installation; measuring new parameters; improving the quality of measurements; minimizing the disturbance to the measured parameter from the sensor presence; deriving new information from conventional techniques; or combining sensor suites with embedded processing to add value to output information. This subtopic solicits proposals for improving airborne sensors and sensor-instrumentation systems in subsonic, supersonic and hypersonic flight regimes. These sensors and systems are required to have fast response, low volume, minimal intrusion and high accuracy and reliability, and include wireless technology. Innovative concepts are solicited in the following areas:

Vehicle Environmental Monitoring
- Nonintrusive air data parameters (airspeed, air temperature, ambient and stagnation pressures, Mach number, air density, flow angle, and humidity at air temperatures as low as -20 deg. F).
- Off-surface flow field measurement and/or visualization (laminar, vortical, and separated flow, turbulence) zero to 50 meters from the aircraft.
- Boundary layer flow field, surface pressure distribution, acoustics or skin friction measurements or visualization.
- Any of the above measurements in hypersonic flow.

Vehicle Condition Monitoring
- Optical arrays for robust flight control surface position and velocity measurement.
- Sensor arrays for structural load monitoring.

- Robust arrays for engine monitoring and control applications. Advanced instrumentation for aeropropulsion flight tests. Thin film and fiber optic sensors, especially those compatible with advanced propulsion system materials such as ceramics and composites, and capable of withstanding the high temperatures and pressures associated with turbomachinery.
- Onboard processing for data condensation, failed sensor identification or other valuable onboard processing capability.

Vehicle Far Field Environmental Monitoring

- Nonintrusive measurements at range of 2-5 kilometers of environmental data (natural and induced flowfields, turbulence, weather, traffic).
- Onboard processing of sensed and telemetered data for integrated storage and strategic presentation to the flight crew.

06.03 Hypersonic Vehicle Design and Systems Technology
Lead Center: LaRC
Participating Center(s): none

Innovative system-oriented research is sought to support, develop, and/or enable advanced hypersonic technologies that could impact the design and optimization of future hypersonic vehicles. The focus is on hypersonic airbreathing vehicles with emphasis on hypersonic cruise airplanes and single- or two-stage-to-orbit vehicles. Design/analysis software/algorithms and graphical user interfaces to the software to address hypersonic vehicle design and performance prediction needs can include the following:

- Conceptual and preliminary design.
- Total multidisciplinary configuration design and optimization.
- Three-dimensional methods for external and internal vehicle/propulsion flowpath analyses (includes CFD and closed form methods or a combination thereof).
- Vehicle sizing and scaling.
- Subsystems design/database including sizing, integration, and networking routines with or without power balance capabilities.
- Methods for design/analysis of cooled leading edges including heat load predictions.
- Inverse design methods.
- Trajectory design, analysis, and optimization.
- Aerodynamic performance prediction methods.

Advanced hardware and systems with the potential to reduce structural weight fraction and/or increase vehicle performance are sought and can include:

- Heat exchangers, reactors, and secondary coolant designs for endothermic fuel systems.
- Propulsion cycles applicable from Mach 0 to 25 and accompanying design and integration techniques.
- Heat-rejection radiators, compact, high-performance convective heat exchangers, and cooling panel design.
- Lightweight, durable coating or insulation systems that can significantly reduce the aerothermal heat load to external/internal surfaces with those improvements.
- MHD propulsion/flowpath.
- Systems for reduction of drag at hypersonic speeds.
- Plasma augmented propulsion.
- Systems for reduction of aeroheating at hypersonic speeds.
- Innovative flight controls.
- Specialized hypersonic fuel systems.

8.2 HUMAN EXPLORATION AND DEVELOPMENT OF SPACE

The mission of the Human Exploration and Development of Space (HEDS) Enterprise is to open the space frontier by exploring, using and enabling the development of space and to expand the human experience into the far reaches of space. In exploring space, HEDS brings people and machines together to overcome the challenges of distance, time and environment. Robotic science missions survey and characterize other bodies as precursors to eventual human missions. In using space, HEDS emphasizes learning how to live and work there and utilize the resources and unique environment. In enabling the development of space, HEDS serves as a catalyst for commercial space development. Throughout, this Enterprise will employ breakthrough technologies and ingenious designs to revolutionize human space flight.

http://www.hq.nasa.gov/osf/heds/

07 Increase Knowledge of Nature's Processes Using the Space Environment

HEDS contributes to the creation of new scientific knowledge by conducting scientific investigations in several related areas. One area focuses on gravity-dependent phenomena using both Earth and space-based facilities. HEDS basic research programs study the fundamental and direct relationship between gravity and certain biological, chemical and physical processes. In these investigations, gravity is used as an experimental variable much as temperature and pressure are in similar studies. The objectives of this topic include understanding the fundamental role of gravity and the space environment in biological, chemical, and physical systems.

07.01: Understanding and Utilizing Gravitational Effects on Molecular Biology and for Medical Applications
Lead Center: JSC
Participating Center(s): none

Microgravity allows unique studies of the effects of gravitational effects on cell and tissue development and behavior. These studies utilize novel and advanced technologies to culture and nurture cells and tissues. These studies also utilize novel and advanced technologies to observe and investigate cells and tissues. Additionally, the ability to manipulate and/or exploit the form and function of living cells and tissues has significant potential to enhance the quality of life on Earth and in space through novel products and services, as well as through new science knowledge generated and communicated. This capability may lead to new products and services for medicine and biotechnology. Specific areas of interest are:

- Development of space bioreactors for culture of fragile cells that have applications including some in biomedical and cancer research. New methods for culturing mammalian cells in bioreactors, including advanced bioreactor designs and support systems, miniature sensors (for measurement of pH, oxygen, carbon-dioxide, glucose, and metabolites within the cell culture fluid medium), and microprocessor controllers.
- Methods for separation and purification of living cells from their products or their stimuli, often, proteins and biomaterials, especially those using electrokinetic or magnetic fields that obviate thermal convection and sedimentation, enhance phase partitioning, or use laser light and other force fields to manipulate target cells or biomaterials.
- Tissue engineering systems which take advantage of microgravity to grow 3-D tissue constructs. Systems include techniques or apparatus for macro-molecular assembly of biological membranes, bio-polymers, and molecular bio-processing systems; bio-compatible materials, devices, and sensors for implantable medical applications including molecular diagnostics, in vivo physiological monitoring and microprocessor control of prosthetic devices.
- Test strategies for evaluating the effectiveness of drugs and biomodulators on growth and physiology of normal and transformed cells. These include methods and apparatus which allow microscopic imaging and biophysical measurements of cell functions, effects of electric or magnetic fields, photoactivation, and testing of drugs or biocompatible polymers on live tissues.
- Methods for measuring specific cellular and systemic immune functions of persons under physiological stress. These include quantitative applications of molecular biology, fluorescence image and flow cytometry, and new methods for measurement of cell metabolism, cytogenetics, immune cell functions, DNA, RNA, oglionuceotides, intracellular proteins, secretory products, and cytokine or other cell surface receptors.
- Novel drug/reagent delivery systems for cell and tissue research, or for human health and performance enhancement and protocols development. These may include micro-encapsulation of drugs, radiocontrast agents, crystals, and development of novel drug delivery systems wherein immiscible liquid interactions, electrostatic coating methods, and drug release kinetics from microcapsules or liposomes can be altered under microgravity to better understand and improve manufacturing processes on Earth or to develop processes for space. Human health and performance applications include methods for improving the controlled release from transdermal drug devices, ionaphoresis, controlled hyperthermia and new drug delivery systems for inhalation and intranasal administration.
- Miniature bioprocessing systems which allow for precise control of multiple environmental parameters such as low level fluid shear, thermal parameters, pH, conductivity, external electromagnetic fields and narrow-band light for fluorescence or photoactivation of biological systems.

07.02 Understanding and Utilizing Gravitational Effects on Biotechnology and Materials Science
Lead Center: MSFC
Participating Center(s): none

NASA has interest in experiments that characterize and utilize the influence of microgravity on biotechnology processes and materials science. Areas of interest include protein crystal growth and structural analysis techniques, separation science and technology, advanced electronic and photonic materials research, metals and alloys technology, glass and ceramic materials technology. Another area relates to microgravity processing approaches such as containerless processing and advanced thermal processing techniques. Innovations are sought in the following:

- Electronic and photonic materials leading to solid-state detectors with improved properties, and controlled crystal growth for scientific and commercial applications. Metallic alloys with improved grain structures by directional solidification and processing involving supercooling and undercooling states.
- Polymers, composites, and other materials that incorporate sensory, effector, and self-repair technologies.
- Simulation capabilities that will elucidate the interaction of transport properties during liquid state processing and can lead to desired microstructures and properties. Experimental design methodologies combining advanced process models, optimization techniques, and control.
- Experiments and theoretical research in separation techniques and protein crystal growth for a greater understanding of such processes in the reduced-gravity environment of space.
- Instrumentation to determine the influence of crystallization parameters on the size and quality as well as growth rates of protein crystals that lead to commercial and medical applications.
- Mathematical modeling, new methods, materials, and techniques to exploit the potential of microgravity for the improvement and understanding of biochemical separation processes.
- Development of technology in eucaryotic cell biology that takes advantage of the unique microgravity environment (or simulated environment) for innovative approaches to drug screening, biological product production, or organ/tissue remodeling.
- Automatic drug separation and purification from plants and cell cultures grown under confined conditions anticipated for prolonged residence in microgravity or off-Earth habitats.
- Advancement of high-yield protein or recombinant drug expression systems that function in cultures grown under simulated microgravity.
- Experimental sample containment, instrumentation, or processing approaches that enhance scientific return or minimize impact to experiment samples. Two examples are (1) containerless processing to control impurities and nucleation sites or allow processing of reactive melts, and (2) provide rapid cooling of the sample to enhance microstructural analysis.
- Thermal insulation or heating approaches that enhance safety and use resources more efficiently.
- Microgravity furnace technology for minimizing power, enhancing thermal axial gradients, and improving quench performance, while maintaining flat solidification interfaces, and minimizing disturbances to the sample.
- Microgravity furnace instrumentation technologies to better understand sample health and experiment status while minimizing the instrumentation's effect on the sample.
- Methods for integrating the furnace with the sample containment system to allow fast, cheap microgravity experiments.
- Advanced modeling techniques that can simulate the slow translation of a sample container relative to a host furnace for gradient processing, rapid translation for quench, and the quench. Methods for simplifying this type of modeling process.
- Technology and instrumentation leading to the formation, interaction and synthesis of particulate materials on Earth and in planetary environments and their application to the establishment of extraterrestrial outposts.
- Materials and studies leading to applications in radiation shielding during human extraterrestrial exploration of space.

07.03 Understanding and Utilizing Gravitational Effects on Plants and Animals
Lead Center: ARC
Participating Center(s): KSC

This subtopic area focuses on technologies that support the NASA Gravitational Biology and Ecology Program in understanding the effects of gravity on plants and animals. The program supports investigations into the ways in which fundamental biological processes function in space, compared to their function on the ground. To conduct these investigations, the program supports both ground and space flight research.

The improved understanding of the role of gravity on plants requires innovative support equipment for observing, measuring, and manipulating the responses of plants to environmental variables.

Areas of specific concern and emphasis include:

- Measuring the atmospheric and radiation environment and optimizing the lighting and nutrient delivery systems for plants.
- Innovative approaches to storage, transportation, maintenance, and in situ analyses of seeds and growing plants.
- Sensors with low power requirements and low mass to monitor the atmosphere and water (nutrient) environment, as well as automated control and data logging systems for the experiment containers to measure performance indicators, such as respiration (whole plant, shoot, root), evapotranspiration, photosynthesis, and other variables in plants.
- Data analysis and control.
- Modular seeding and/or planting units to minimize labor.
- Sensors for atmospheric, liquid and solid analyses, including atmospheric and liquid contaminants such as ethylene and other biogenic compounds as well as analyses of hydroponic and solid media for N, P, K, Cu, Mg and micronutrients.
- Remote sensors to identify biological stress.
- Expert control systems for environmental chambers.

The improved understanding of the role of gravity on animals requires studies, which range from organism development, including gametogenesis through fertilization, embryonic development and maturation, through ecological system stability. Studies may include a variety of processes such as metabolism and metabolic control, through genetic expression and the control of development. Of particular interest are technologies that require minimal power and can non-invasively measure physical, chemical, metabolical and development parameters. Such measurements will ultimately be made in environments at one or more of several gravity ranges, e.g., "microgravity" (10-2 to 10-6 x g), "planetary" gravity (1 x g (Earth); 0.38 x g (Mars) or 0.12 x g (Moon)) or hypergravity (up to 2 x g). But, refined and stable measurements are as important as gravity independence. Of interest are sustained instrument sensitivity, accuracy and stability, and reductions in the need for frequent measurement standardization. Parameters requiring measurement include, e.g., pH, temperature, pressure, ionic strength, gas concentration (O_2, CO_2, CO, NO_2, etc.), and solute concentration (e.g., Na+, K+, Ca2+, Mg2+, SO_4 2-, Cl-, PO_4 3-, etc.). In the case of new techniques and instruments, a clear path toward miniaturization, reduction in power demands and increased space worthiness should be identified.

Interests applicable to plant, microorganism, and animal study applications include:

- Expert data management systems.
- Capabilities for specimen storage, manipulation and dissection.
- Video-image analysis for biospecimen (cell, animal, plant) health and maintenance.
- Sensors for primary environmental parameters and microbial organisms.
- Biotelemetry monitors and biological monitors carried on remotely controlled spacecraft.

07.04 Exploiting Gravitational Effects for Combustion, Fluids, Synthesis, and Vibration Technology
Lead Center: GRC
Participating Center(s): none

NASA seeks innovative proposals for products to improve the operation and safety of orbiting spacecraft based on chemical and physical processes that exploit the microgravity and partial gravity environment. Also sought are products for application to NASA missions involving Mars and the Moon and for ground-based application and commercialization based on principles, understandings, or testing in simplified, non-convective microgravity and partial gravity fields.

For some demonstrations to support product development, the NASA Lewis Research Center can provide access and assistance to outside investigators in its unique facilities, including the Space Experiment Laboratory, the 2.2-second and 5.2-second drop towers, and parabolic-trajectory (20 seconds of low gravity) aircraft (See Section 5.14). Specific areas of interest are:

- Products based on combustion or related chemical reactions in gaseous, liquid, solid, or mixed phases for application to spacecraft operational needs or to derived ground systems, aided by principles, models, or demonstrations validated in the simplified environment of microgravity and partial gravity.
- Products based on physical contact or transport in fluid, dispersed, or mixed phases for application to spacecraft operational needs or to derived ground systems, aided by principles, models, or demonstrations validated in the simplified environment of microgravity and partial gravity.
- Small-scale intermetallic, ceramic, or similar products produced through combustion synthesis in solid, filter-flow, thermite, or other reactions, with product uniformity, composition, or yield controlled or improved by exposure to the non-convective microgravity and partial gravity environment.
- Products to measure, isolate, or control acceleration, vibration, or jitter for application to spacecraft operational needs or to space experiment payloads or to derived ground systems.
- Sensors, instrumentation, and diagnostics systems for application to non-disturbing measurement of chemical, thermal, or flow parameters in microgravity and partial gravity or to derived ground systems, based on principles, models, or demonstrations validated in microgravity or partial gravity.
- Products to promote or improve fire safety through prevention, detection, suppression, or post-fire restoration for application to spacecraft or to derived ground systems, aided by principles, models, or demonstrations validated in microgravity or partial gravity.
- Fluid dynamic phenomena associated with materials processing, protein crystal growth and separation processes in microgravity and partial gravity as well as in the Earth-bound environment.
- Technology that explains, enables or improves combustion and fluid processes in partial gravity environments to promote application of these processes to NASA's missions involving Mars and/or the Moon.

08 Explore and Settle the Solar System

The International Space Station Program and Mars Exploration studies have defined technology and research needs that are critical to their individual goals. These include: research on human adaptation to the space environment; regenerative and bioregenerative life support; telerobots and robot assistants; space and planet surface suits; utilization of indigenous resources for propellants, life support consumables, radiation protection, and construction materials; micro- and nano-technologies, manufacturing processes, and advanced materials. All are sought to enable humans to live and work in space or on a planet, to enhance performance, reduce cost, and maintain the health and well being of the crew.

08.01 In-Situ Resources Utilization (ISRU) of Planetary Materials
Lead Center: JSC
Participating Center(s): none

Significant benefits for future human missions to the Moon, Mars, and other planetary bodies may be attained by making maximum use of local, indigenous materials as a source for propellants, life support consumables, radiation protection, and construction materials. By pursuing the philosophy of "make what you need at the planet instead of bringing it all the way from Earth", in-situ resource utilization (ISRU) can result in reduction of mass requirements for the exploration mission, reduction in risk, and reduction in cost of the mission. It can also enable industrial and commercial participation in planetary exploration and expand human presence on the planet surface. One example of in-situ propellant production employs the hydrogen reduction process for extracting oxygen from lunar minerals and glass. In addition, a number of techniques have been proposed for extracting and storing oxygen from the carbon dioxide atmosphere of Mars. In general, these processes require a number of subsystems, each of which could benefit from innovative approaches and technology advances. It is also possible that water could be extracted from permafrost deposits located at shallow depths in some locations on Mars. Key goals are to minimize the mass which must be brought from the Earth (including the equipment required to move or process the material), minimize power consumption, be truly innovative, and use methods not already in the literature. Areas for investigation of specific methods and processes for in-situ resource utilization include the following:

Surface Resources

- Methods and systems for extracting, processing, and manufacturing in-situ materials that can be used for construction of habitable structures on the Moon or Mars. New methods for constructing buildings, radiation-shielding structures, and tunneling techniques are needed. Novel methods for underground development of habitable structures (perhaps using natural features such as caves or lava tubes) on the Moon or Mars are also needed.
- Methods for processing surface materials into useful equipment (e.g., solar panels, radio antennas, replacement parts, etc.) which require no further manufacturing or assembly.
- Methods and systems for digging, sorting, mineral separation, and transporting lunar regolith or other materials to a reactor. Such systems should be lightweight, efficient, and capable of operating with minimal human supervision.
- Methods for extracting oxygen from lunar regolith that are power efficient and require a minimum of Earth-supplied reagents and consumables. Alternatives and improvements to previously-studied methods, such as reactors that expose lunar regolith to hydrogen gas at elevated temperature, are of interest. However, emphasis should be placed on innovative designs that minimize power requirements.
- Microbial methods for extracting oxygen, decomposing water, and extracting solar wind hydrogen from soils (typically present on the Moon at 50 parts per million levels) from the Moon as an attractive alternate approach to propellant and consumable production.
- Methods for extraction, collection and transportation (if required) of water that may be present on the surface or subsurface of Mars, which minimize power requirements, and equipment mass which must be brought from Earth. Proposals in this area should recognize the uncertainty and potential variability of both the location and abundance of such water.

Atmospheric Resources

- Methods to condense water vapor from the Mars atmosphere that are low mass or can be constructed from local materials with a minimum of equipment that must be brought from Earth.
- Microbial methods for extracting oxygen from the Mars atmosphere, or for decomposing water.
- Innovative processes and alternative approaches for extracting propellants and/or consumables including oxygen from the Mars atmosphere which have low power requirements and minimize the amount of equipment that must be brought from Earth. Processes currently being investigated include Sabatier/water-electrolysis reactor, reverse water gas shift reactor, and solid-oxide electrolysis (zirconia) cells. Oxygen extracted from the Mars atmosphere may be used for: production of propellant for transportation systems, production of oxygen for life support system gases, and production of cryogenics for extravehicular activity suits. Systems should be capable of operating autonomously, independent from continual Earth-based control.

Current scenarios for Mars exploration envision the following production needs for ascent oxygen propellant to support a single mission: 1 to 2 metric tons (for Mars robotic missions) and 30 to 40 metric tons (for Mars human missions).

08.02 Human Health Maintenance/Countermeasures and Spacecraft Environmental Monitoring, Safety, and Protection
Lead Center: JSC
Participating Center(s): ARC, DFRC, JPL

Human presence in space requires an understanding of the effects of microgravity and other components of the space environment on the physiological systems of the body and on the psychology of the crew. A variety of environmental monitoring and biomedical activities to protect crew health and to counter the effects of space on human physiology is required. Countermeasures must be developed to oppose the deleterious changes that occur in space or upon return to Earth. Health care and medical intervention also must be provided over extended-duration missions. As launch costs are extremely sensitive to mass and volume, sensors and instruments must be small and light with an emphasis on multi-functional aspects. Low power consumption is a major consideration, as are design enhancements to improve the operation, design reliability, and maintainability of these instruments in microgravity. As the efficient utilization of time is extremely important, innovative instrumentation setup, ease of usage, improved astronaut (patient) comfort, non-invasive sensors, and easy-to-read information displays are all-important considerations.

Major research disciplines include: endocrinology, immunology, hematology, microbiology, muscle physiology, drug delivery systems, radiation biology, toxicology, and air quality and water quality monitoring.

Human Health Monitoring and Countermeasures

- Methods and equipment to maintain and assess levels of aerobic and anaerobic physical capability.
- Methods to monitor physical activity and loads placed on different segments of the human body.
- Exercise equipment able to load the musculoskeletal and cardiovascular systems and monitor, record, and provide feedback about performance.
- Approaches for sustaining, maximizing, assessing, and modeling individual as well as team performance.
- Countermeasures against deleterious changes in body systems in flight or upon returning to the ground. Changes include space adaptation syndrome effects such as space motion sickness, in-flight loss of muscle and bone mass, post-flight orthostatic intolerance, and post-flight reduction in neuromuscular coordination.
- Assessment of gas bubble formation or growth in the body after in-flight or ground-based decompression, and to prevent or minimize associated decompression sickness.
- Means to apply artificial gravity and reduce deleterious effects associated with short-arm centrifuges.
- Approaches to achieve health care and intervention within the operational constraints of space flight, including pharmaceuticals having extended shelf-life, diagnostic methods and procedures, medical monitoring, dental care and surgery, and blood replacement technology.
- In-flight procedures and techniques for assessing the human metabolism of proteins, carbohydrates, lipids, vitamins, and minerals.
- In-flight specimen collection and analysis to evaluate physiological and metabolic and pharmacological responses of astronauts. Non-invasive methods to measure crew performance and related factors.
- Novel software methods for documentation, storage, retrieval, analysis, and diagnosis of crew health.

Reliable means are required for assessing emotional state and operational efficiency of crewmembers during long duration spaceflight:

- Converging indicators of autonomic reactivity, psychomotor skill and cognitive function should be used to evaluate crewmember's functional state.
- These measures should also allow determination of whether or not to modify crewmember's workload (for example) and can be used to evaluate the effectiveness of countermeasures.

Human Sensors and Instrumentation

- Instrumentation to be used for in-flight and ground-based studies for reliable and accurate non-invasive monitoring of human physiological functions, such as the cardiovascular, musculoskeletal, neurological, gastrointestinal, pulmonary, immuno-hematological, and hematological systems.
- Improve non-invasive methods to evaluate the functioning of the cardiovascular, neurological, musculoskeletal, and pulmonary systems.
- Non-invasive instruments to provide quantitative data to establish the effectiveness of an exercise regimen in ground-based research.
- Smart sensors capable of sensor data processing and sensor reconfiguration.
- Ultrasonic doppler systems for blood flow analysis.
- Virtual medical instrumentation.
- Automated biomedical analysis.
- Microgravity blood, urine, and respiratory gas analyzers.
- Microgravity refrigeration systems for the storage of biological samples and incorporating refrigerants acceptable for use in a spacecraft environment.

Telemedicine

Telemedicine, the integration of telecommunications, computer, and medical technologies, permits NASA medical doctors and researchers on Earth to monitor the health and physiology of astronauts in space. Innovative technologies are being sought to support the current flight programs (Space Shuttle and the International Space Station), and future Space exploration programs.

Innovations in the following areas of telemedicine technology are being sought:

- Biomedical monitoring and sensing involves the acquisition, processing, communication, and display of electrical, physical, or chemical aspects of a human's health or physiologic state. This mode of telemedicine may be used for real time monitoring or for store-and-forward applications.
- Interactive telecommunication, with parties at both ends communicating via voice and video in real time (e.g., patient-physician consultations), and store-and-forward, with video and audio clips transmitted for review at a later time (e.g., physician-physician consultations that are not dependent on immediate review).
- Static imaging-single-frame visual images, typically of much higher resolution than is required for interactive consultations (which are generally of a resolution similar to a commercial TV picture). Examples include teleradiology, telepathology, and teledermatology. Although configured as a store-and-forward technology, static imaging may also be done in real time.
- Autonomous systems for support of medical care and training, where the experience of experts on the ground is programmed into a computer system to provide that expertise to flight personnel in space.

The data rate and interactivity of the telemedicine modalities are quite different. The hardware, software, and communications requirements for these modalities are likewise very different. Information indexing and retrieval, and the management of large databases are also essential components of telemedicine.

The following telemedicine enhancing technologies are of particular interest:

- Small, portable, medical diagnostic equipment (digital X-ray and ultrasound imaging systems) capable of being deployed and used in space, with provision for downlinking the data to physicians on the ground.
- Non-invasive, in-vivo, biosensors for monitoring blood chemistry, gases, calcium ions, electrolytes, cellular components, proteins, lipids, and hormones.
- Real time, in-vitro, urine chemistry sensors for automated urine chemistry analysis in a smart toilet.
- Small, low power, wireless communication systems, for bidirectional data/ command communication between instrumented astronauts and spacecraft subsystems.
- Advanced human/computer interface systems for improved immersion in virtual and augmented realities in support of medical operations.
- Expert systems to support medical diagnosis and treatment.

- Virtual reality medical training system to support in-flight training on medical diagnosis and procedures.
- Augmented reality supervisory system to support medical treatment and minor surgery.
- Improved data mining technology for on-orbit access to medical and training databases.
- Data compression technology that permits accurate medical diagnosis after decompression.

Proposals must support telemedical applications and provide innovation beyond current commercial technology. Telemedicine air/ground communications are supported through existing spacecraft communication channels for voice, video, and data.

Environmental Monitoring Technologies

- Real-time, quantitative, compound-specific analyzers for trace contaminants in spacecraft atmospheres and/or recycled water. Of particular interest are the quantitative measurement and removal of organic contaminants. These sensors are used for support of control functions or safety precautionary measures including providing outputs for caution and warning displays.
- Maintenance of microbial quality of the atmosphere, water and surfaces during space flight and means of assessing their effectiveness, including new, clinical microbiological methods for rapid identification of pathogens, methods for measuring biofilms, and novel systems for sterilization.
- In-flight monitoring of non-ionizing, neutron and charged particle radiation for determining interior and exterior environment of manned spacecraft, organ doses and the cytogenic and carcinogenic effects of protons and heavy ions, especially at low doses; measurement of effectiveness of radio-protectants and development of new radio-protectants against acute and late cellular effects of particulate and high energy cosmic radiation; development of biomarkers and amplified assays for measuring radiosensitivity and genetic damages by charged particle radiation in human cells; development of computer biophysical models for organ dose calculation and for extrapolation of radiation data from cells to humans.

08.03 Spacecraft Life Support Infrastructure
Lead Center: JSC
Participating Center(s): ARC, JPL, KSC, MSFC

Advanced life support systems are essential for the success of future human planetary exploration. Striving for self-sufficiency and autonomous operation, future life support systems will integrate physical, chemical, and biological processes. These hybrid systems, which include plant growth systems for the production of food and oxygen and utilization of recovered wastes, represent an additional closure of regenerative life support systems to further reduce mass and to promote self-sufficiency. Requirements include safe operability in micro-and partial-gravity, high reliability, minimal use of expendables, ease of maintenance, and low system volume, weight and power. Innovative, efficient, practical concepts are desired in all areas of regenerative physicochemical and biological processes for the basic life-support functions of air revitalization, water reclamation, waste management, plant food production, and sensors and controls. Also innovative, cost-effective concepts are desired to assess, predict, control and enhance the effect of microgravity and partial-gravity on the operation and performance of physicochemical and biological life support technologies including approaches to safely integrate flight experiments into the International Space Station. In addition to these space exploration related applications, innovative regenerative life support approaches that could have terrestrial application are encouraged. Proposals should strive to conduct Phase-II experimental development that could be integrated into a functional life support system. Areas in which innovations are solicited include the following:

Air Revitalization: Oxygen, carbon dioxide, water vapor, and trace gas contaminant concentration, separation, and control techniques.

- Separation of carbon dioxide from a mixture primarily of nitrogen, oxygen, and water vapor to maintain carbon dioxide concentrations below 0.3 % by volume.
- Separation of nitrogen and oxygen from carbon dioxide to reduce concentrations of nitrogen and oxygen to less than 0.2 % by volume.

- Removal of trace contaminant gases from cabin air with advanced regenerable sorbent materials, improved oxidation techniques or other methods.
- Compression of a high humidity 0.167 kg/hr (0.367 lb/hr) carbon dioxide stream from a very low pressure level of 0.7-1.4 kPa (0.1-0.2 psia) up to moderate storage pressure level of 345-517 kPa (50-75 psia).

Water Reclamation: Efficient, direct treatment of waste water (e.g., urine, wash water, and condensates) without requiring expendables to produce potable and hygiene water including stabilization of waste water and purge gases prior to storage, processing, or overboard-venting. In particular, processes are required that reduce impurities in composite waste streams from greater than 1000 ppm total organic carbon (TOC) content to less than 0.25 ppm TOC and inorganic salts from greater than 1000 ppm dissolved solids to less than 50 ppm.

- Removal of ammonium ion from bioreactor process effluent streams from 1000 ppm to less than 0.25 ppm.
- Post-treatment of processed water by in-situ organic removal from 100 ppm TOC to less than 0.25 ppm TOC and removal of microorganisms from >ten million CFU per ml to one CFU per ml.
- Methods to optimize two-phase fluid movement, measurement and phase separation of waste water in a microgravity environment.
- Development of nitrifying bioreactors capable of at least 75% nitrification of a 1000 ppm ammonium feedstream.
- Methods to enhance oxygenation of water in a microgravity environment, specifically to levels above 25 ppm dissolved oxygen.
- Methods of cold sterilization, including filtration, ultraviolet radiation and in-situ-generated hydrogen peroxide.
- Non-expendable methods to control urine solids formation (e.g., calcium phosphate), compatable with a bioprocessing system (i.e., no acid).
- Methods to minimize or limit biofilm formation on fluid handling components (such as electromechanical flowmeters, regulators, checkvalves, etc).
- Methods to enhance biofilm formation on polymeric and/or ceramic substrates in metal housings.

Waste Management: Biological and physicochemical technologies for recovering resources (e.g., carbon dioxide, water, nitrogen, hydrogen, etc.) from wastes (trash, plant biomass, human fecal wastes, etc.). Existing technology examples follow for which significant improvements may be proposed, but new technology approaches are encouraged.

- Waste stabilization and pretreatment, including microbial control techniques.
- Waste processing techniques such as, but not limited to, incineration, aerobic biodigestion, anaerobic biodigestion, wet oxidation, supercritical oxidation, steam reforming, electrochemical oxidation and catalytic oxidation. Any effective waste treatment technology can be considered.
- Product and by-product post-treatment technologies that eliminate undesirable by-products such as nitric oxide and sulfur dioxide and stabilize the product for storage.

Plant Growth and Food Production: Technologies for the controlled environment production of crop plants to produce food and to contribute to the reclamation of water, purification of air, and recovery of resources.

- Crop Lighting: 1) sources for plant lighting such as, but not limited to, high-efficiency lamps or solar collectors; 2) transmission and distribution systems for plant lighting including, but not limited to, luminaires, light pipes and fiber optics; and 3) heat removal techniques for the plant growth lighting such as, but not limited to, water-jackets, water barriers, and wavelength-specific filters and reflectors.
- Water and nutrient delivery systems, including 1) technologies for production of crops using hydroponics or solid substrates; 2) water and nutrient management systems; 3) sanitation methods to prevent excessive build-up of microorganisms within nutrient delivery systems; 4) regenerable media for seed germination plant support; 5) separation and recovery of usable minerals from wastewater and solid waste products for use as a source of mineral nutrients for plant growth.

- Mechanization and automation of propagation, seeding, and plant biomass processing. Plant biomass processing includes harvesting, separation of inedibles from edibles, cleaning and storage of edibles (seed, vegetable, and tubers) and removal of inedibles for resource recovery processing.
- Facility or system sanitation methods to prevent excessive build-up of microorganisms within nutrient delivery systems.
- Health measurement of plant growth systems from parameters such as rate of photosynthesis, transpiration, respiration, nutrient uptake. Data acquisition should be non-invasive or remotely sensed using spectral, spatial, and image analysis. System modeling and decision-making algorithms may be included.

Sensors: Significant improvements in accuracy, operational reliability, real-time multiple measurement functions, in-line operation, self-calibration, and low energy consumption for monitoring and control of the life support processes. Species of interest include nutrient composition of plant growth hydroponic delivery systems, dissolved gases and ions in water reclamation processes, and major atmospheric gaseous constituents in air revitalization processes. Both invasive and non-invasive techniques will be considered.

08.04 Space Crew Accommodations and Performance Enhancements
Lead Center: JSC
Participating Center(s): none

The goal of this subtopic is to improve crew and ground operations performance and productivity in a system context, documenting the cost-effectiveness of the improvements; and to develop innovative concepts in crew accommodations, equipment, and computer-based support which will enable complex, future human space missions including missions of 5 years without resupply.

As NASA develops new operational capabilities to support multiple manned missions, and long duration and long distance missions, dramatic improvements will be needed in crew and ground operations performance and productivity. The crew will be increasingly autonomous from the ground, with significant control and maintenance responsibilities. However, the crew will not have the time or expertise to function primarily as operators in an onboard control center or as maintenance personnel. Science activities and operations will produce large volumes of data that will influence decisions about subsequent science activities and operations. Responsibility for updating operations software and associated data and knowledge bases will shift from software specialists to engineers, operations personnel and crew. Communications constraints and increased autonomy will limit ground support. Budgetary constraints and mission complexity will drive innovations in system design, crew accommodations and equipment to make ground support, mission preparation and training more productive.

Specific areas of interest for innovations in space crew accommodations and performance enhancements include:

Human Factors
Methods to better predict and analyze crew performance and environmental variables will facilitate effective mission planning and task/function allocation. Better equipment for crew support will enable enhanced performance. Specific areas of interest for innovations in human factors areas include:

- Advanced methods for collecting and analyzing human performance with minimal human operator involvement. For example, methods for automatically identifying categories of performance from videotaped records, such as time spent at a given task, time spent in translation, and time spent in interaction with other crew members.
- New technology in the area of passive human posture, position tracking, and kinematics in 3D capable of accuracy better than 5 mm, with sample rates greater than 50 Hz for the whole body, all the major limbs, and head.
- Technologies or tools to evaluate, measure or enhance habitability including spacecraft interior layout, illumination and material reflectivity, and lightweight acoustic control methods. An area of special interest would be in techniques for reconfiguring spacecraft habitable areas including stowage, galley, sleep

compartments, waste management systems, etc., for optimal use in both micro-g during transit to a planetary surface, and in partial-g on the planetary surface.
- New calculation and mapping techniques for acoustics and vibration, with emphasis on potential impact to habitable environments.
- New technology in illumination, particularly solid state (LED) technology. Luminaires with life times greater than 50,000 hours, with selectable color temperatures ranging between 3000 and 6000 deg Kelvin. Efficiencies of 40 to 50 lumens per watt are desired.
- New technology for illumination modeling, evaluation, and design with particular attention to real-time displays of shadowing, glare, bloom, and energy distribution.

Onboard Crew Support Systems
Extended human exploration missions, including Earth-orbit and planetary transit and surface missions, require new and improved food processing and storage systems, personal hygiene systems, crew equipment, housekeeping techniques, and in-flight maintenance tools, techniques, and software to ensure optimum crew performance and productivity. Specific areas of interest include the following:

Food Systems
- Extended duration missions require food with 3 to 5 years of shelf life. This shelf life extension may be accomplished through packaging and preservation technologies which minimize waste, and improve acceptability and food safety.
- Long shelf life palatable dairy products are needed.
- Food packaging waste is a problem for all missions and methods for reducing food waste are desired. Food waste on Shuttle is currently returned to Earth for disposal.
- Advanced food preparation equipment and processes for heating, chilling, rehydration, ease of handling in micro-gravity, and food service onboard space vehicles are also needed. Current capabilities include a forced air convection oven for Shuttle and a microwave/forced air convection oven is being developed for the International Space Station. Shuttle has no freezers or refrigerators, but these are planned for the International Space Station.
- Processing and preparation of chamber-grown wheat, rice, soybeans, sweet potatoes and potatoes into edible foods in partial gravity (1/6 - 1/3 g) is a high priority for planetary based missions. Methods for converting these crops to edible ingredients and/or foods in a closed environment, while optimizing crew time, volume, power, water usage, and generated waste are needed. Products of interest include oil, sugar, and meat and dairy analogs.

Crew Equipment
- Personal hygiene systems in a zero-gravity environment. Examples: total body cleaning, hair grooming, cleansing agents compatible with closed-loop life support systems.
- Personal crew equipment: flame and soil resistant clothing, portable lighting, safety and emergency equipment, and body and equipment restraints.
- Housekeeping for zero-gravity including: habitat cleaning, trash management, apparel cleaning, particulate reduction and control, and cleansing agents compatible with closed-loop life support systems.
- Tools, techniques, and software for an in-flight maintenance system to maintain a complex system, including expert diagnostics, in-flight manufacturing tools/techniques.

Crew Training and Space and Ground Operations
Dramatic improvements will be needed in crew and ground operations performance and productivity as NASA develops new operational capabilities to support multiple manned missions, and long duration and long distance missions. Robotic, vehicle and support systems will be required to be more robust, autonomous and intelligent, and more maintainable. These capabilities will allow operators to "buy time" by increasing system mean time between failures, predicting when intervention will be needed, managing degraded operations, and using functional redundancy. Advanced capabilities for information and data analysis and presentation, onboard planning, execution and fault management will be needed to assist the crew. Sophisticated training and maintenance support systems and a robust knowledge base will be needed onboard, and will need to be well integrated with increasingly

advanced control and maintenance systems. Ground support operations will need to be redesigned to support the increasing autonomy of space systems and onboard crew. There will need to be advanced support for distributed and adjustable command responsibility, and distributed and flexible training. Significantly more productive and intuitive approaches are needed to updating, adapting, testing and certifying advanced distributed operations software and knowledge bases during missions. Specific areas of interest in the areas of crew training, and in flight and ground operations, include:

Crew Training and Maintenance Support Systems

- Flexible training and tutoring systems for mission operations support, including distributed cooperative training, virtual reality training, intelligent computer-based training, and authoring tools.
- Integration of training with advanced control and maintenance systems.
- Tools to collect/capture and tailor design-time information for use in developing training materials.
- Procedures or technology for evaluating effectiveness of innovative training methods.

Data Management, Data Analysis, and Presentation and Human Interaction

- Methods for selecting and summarizing vehicle systems and payload data relating to status and events, to support crew and ground awareness, operational decision-making, and management by exception and opportunity rather than by continuous or scheduled monitoring.
- Human interaction methods for collaboration, cooperation and supervision of intelligent semi-autonomous systems.
- Goal-driven collaborative data analysis systems capable of adaptation and learning.
- Simple systems for notification and coordination, including natural language interfaces.
- Immersive environments: real-time environments to enhance a human operator's ability to interact with large quantities of complex data, especially at distant locations.
- Intelligent data analysis techniques: capabilities to interpret, explain, explore, and classify large quantities of heterogeneous data.

Robust Planning, Operations, Fault Detection, and Recovery with Distributed Adjustable Command Responsibility

- Onboard planning, sequencing, monitoring, and re-planning of activities, including systems and crew activities.
- Flexible management of the actions of subsystems within the larger context of system flight rules and constraints.
- Flexible and robust fault management approaches that use system models, "buy time" for human intervention and maintenance, and learn from human operators during and after the interventions.
- Approaches to distributed and adjustable command responsibilities among systems, crew and ground.
- Model-based continuous estimation of the likelihood of critical events, including human errors, to provide warnings of potential events and their consequences, and to suggest appropriate countermeasures.
- Integration of systems for fault management, maintenance and training.

Operations Knowledge Management and Software Updating

- Systems and processes for crew and ground operators to quickly and effectively define, update, test and certify operational knowledge and rule bases before and during missions, designed for reuse in autonomous systems and in training.
- Tools for incorporating and using engineering data and specifications (about equipment and its operating modes and failures and about operations procedures) into operations knowledge and model-based autonomous systems.
- Tools and environments to support modification and validation of knowledge bases (models of activities, equipment and environment) in intelligent autonomous software by operators, to capture methods and knowledge used by operators during interventions and to collaboratively adapt to unanticipated circumstances.
- Simulation environments and tools for use in designing and testing intelligent semi-autonomous systems.

08.05 Extravehicular Mobility/Activity
Lead Center: JSC
Participating Center(s): none

Advanced extravehicular activity (EVA) systems are necessary for the successful support of future human space missions. Complex missions require innovative approaches for maximizing human productivity and for providing the capability to perform useful work tasks. Requirements include reduction of system hardware weight and volume; increased hardware reliability, durability, and operating lifetime (before resupply, recharge and maintenance, or replacement is necessary); reduced hardware and software costs; increased human comfort; and less-restrictive work performance capability in the space environment, in hazardous ground-level contaminated atmospheres, or in extreme ambient thermal environments. All proposals must lead to specific Phase-II experimental development that could be integrated into a functional EVA system. Additional design information on advanced EVA systems can be found in the EVA Technology Roadmap of the EVA Project Plan.

Areas in which innovations are solicited include the following:

Environmental Protection
- Radiation protection technologies that protect the suited crewmember from radiation particles.
- Puncture protection technologies that provide self-sealing capabilities when a puncture occurs and minimizes punctures and cuts from sharp objects.
- Dust and abrasion protection materials to exclude dust and withstand abrasion.
- Thermal insulation suitable for use in low ambient pressure, but not vacuum, environment.

EVA Mobility
- Space suit gloves, produced with size-reproducible manufacturing processes, that provide highly dexterous hand, fingers, and thumb mobility and tactile sensitivity, and that incorporate active thermal control capability for removing and/or adding heat, depending upon external ambient thermal conditions and hand-grasp surface temperature.
- Space suit soft joints that provide dual-axis capability and low torque in rotational components and that also minimize stowage volume, and that are lightweight, low cost, and large range.
- Space suit shoulder that can accommodate large range of suit pressures from 3.5 to 8.3 psi, and is low torque, lightweight, and low cost.
- Space suit low profile waist-bearing that maximizes torso rotation that is necessary for partial gravity mobility requirements and is also lightweight and low cost.

Life Support System
- Long-life and high-capacity chemical oxygen storage systems for an emergency supply of oxygen for breathing, such as:
  - Innovative alternatives to chlorate candles that provide reliable backup oxygen supply.
  - Potassium superoxide/fullerine stowage of oxygen to reduce volume.
- Low-venting or non-venting regenerable individual life support subsystem(s) concepts for crewmember cooling, heat rejection, and removal of expired water vapor and carbon dioxide.
- Fuel cell technology that can provide power to a space suit.
- Convection and freezable radiators that will be low cost and weight for thermal control.
- Water membrane evaporator that can provide reliable cooling at Mars pressure.
- Microencapsulated wax and carbon brush garments that provide direct thermal control to crewmember.
- High reliability pumps and fans.
- CO_2 and humidity control devices which, while minimizing expendables, function in a CO_2 environment.

Sensors/Communications/Cameras
- Information displays and input and output interfaces for use by the EVA-suited individual, including displays for obtaining status information of and/or controlling systems performance or work-task related equipment.

- CO_2, bio-med, and core temperature sensors with reduced size, lightweight, increased reliability, and packaging flexibility.
- IR camera that displays temperature of environment for safe handling of objects and are integratable into a spacesuit.
- Visual camera that provides excellent environment awareness for crewmember and public and are integratable into a spacesuit.
- Microphone on glove that detects flows and proper operation of equipment by glove sound sensors.
- Mini-mass spectrometer that detects N_2, CO_2, NH_4, O_2, and hydrazine partial pressures.
- Radio/laser communications that provides good communications among crew and base.

Integration
- Robotics interfaces that permit autonomous robot control by voice control via EVA.
- Minimum loss airlock providing quick exit and entry.
- Recharge and checkout systems that lower EVA overhead time for crew.
- Work tools that assist the EVA crewmember during movement in zero-gravity and at worksites. Specifically, devices that provide temporary attachments, that rigidly restrain equipment to other equipment and the EVA crewmember, and that contain provisions for tethering and storage of loose articles such as tool sockets and extensions.
- Surface mobility devices for EVA crewmembers.

08.06 Robotic Manipulators, End-Effectors and Joints
Lead Center: JSC
Participating Center(s): KSC

Proposals are solicited for innovative concepts that will both increase robotic dexterity manipulation capabilities, and reachability, and also increase capabilities for humans to interact with and to control robotic systems to perform on-orbit operations while minimizing the workload to EVA and IVA astronauts, and ground operators.

Robotic Manipulators, End-Effectors, and Joints
Proposals are sought which include improvements to robotic joints, actuators, end-effectors, tools, and mechanisms. Proposals should address issues associated with space compatibility. Specific areas of interest include the following:

- Increased power-to-weight ratio and reduced scale actuators including magnetostrictive motors and synthetic muscles.
- Miniaturized actuator control and drive electronics.
- Miniaturized sensing systems for manipulator position, rate, acceleration, force and torque.
- Robotic grasping and handling systems that accommodate existing EVA tools, including human-sized multi-fingered dexterous end-effectors.
- Anthropomorphic systems.
- Sensor-guided tools providing higher precision or lower contact forces.
- Planetary robotic mobility systems and devices. Robots will be needed to work with and transport humans and equipment on a planetary surface. Examples include novel rover drive systems, suspension systems, and manipulators systems.
- Low-mass and low power devices for site setup, operation, and planetary surface exploration. Novel mechanisms are needed to enable human exploration and habitation of planetary bodies. Examples include site clearing and setup devices, equipment deployment devices, sample collection and manipulation devices, instrument placement devices, and the actuation components for these devices.
- An electrically-operated robotic arm suitable for handling moderately heavy payloads from a mobile vehicle in a hazardous environment. Unit should be suitable for use in a Class One, Division One, Group A environment.

Human/Robotic Interface
Proposals that improve operator efficiency via advanced displays, controls and telepresence interfaces, improve ground based robotic control technology, and improve the ability of humans and computers to seamlessly control robotic systems are sought. Specific technology requirements include the following:

- Tactile feedback devices that provide operator awareness of contact between work space objects and the robot structure. Key aspects of this technology are ergonomics and safety.
- Force feedback devices that provide operator awareness of manipulator and payload inertia, gripping force, and forces and moments due to contact with external objects. Key aspects of this technology are ergonomics and safety.
- Stereo graphic display systems that provide high-fidelity depth perception, field of view, and high resolution.
- Ground-based control technology which is able to compensate for time delays of several seconds.
- User interface that does not require the operator to wear exoskeletons to control the motions of the robot.
- Tracking position and orientation of user appendages, (i.e., head, arms, fingers, eyes) for the purpose of providing motion commands to the robot. Key aspects of this technology are to free the operator of any exoskeletons or devices attached to the body that impede or restrict operator movements.
- Adaptive fault tolerant software: Systems capable of dynamic reconfiguration and learning.
- Intelligent autonomous systems: Artificial intelligence based systems and architectures, with provision for crew oversight.

08.07 Advanced Manufacturing and Nanotechnology
Lead Center: JSC
Participating Center(s): none

Proposals are sought to establish and maintain state-of-the-art applications of nanotechnology, manufacturing, hardware production, and manufacturing processes, as they relate to future human spacecraft. Proposals in the following areas should be focused on hardware or software products.

Nanotechnology
Applications of nanotechnology should focus on long-duration space missions and habitats. Revolutionary designs and concepts are sought using the extraordinary properties of single-wall carbon nanotubes in areas such as high strength materials and composites, energy storage, nanoelectronics, and thermal protection, among others. Nanotube composites (polymer or metal matrix) are of particular interest because of the great possibilities of using these materials with ultra-high strength. Also of interest are innovative techniques for bulk production of single-wall nanotubes, and production of exceptionally long and/or aligned nanotubes, necessary for such applications as composites.

Manufacturing Technology
Rapid prototyping using the Stereolithography (SLA) and Fusion Deposition Modeling (FDM) techniques to produce functional prototypes and working models, including use of single-wall nanotubes. Composites manufacturing using fiber placement, filament winding, laminations, pultrusion, and Resin Transfer Molding (RTM) techniques. Manufacture and precision of miniature mechanical components. Friction stir weld and laser weld processes.

Machine Tool Programming
Program and verify computer-numerical control (CNC) machinery using computer-aided design/computer-aided manufacturing (CAD/CAM) programs. Machine tool operations of interest include multi-axis milling.

08.08 Cryogenic Fluids, Handling, and Storage
Lead Center: GRC
Participating Center(s): JSC

Component or concept proposals are being solicited to improve the performance, operating efficiency safety and reliability of cryogenic fluid storage and handling in all gravity environments (10^{-6} g to 1 g) and Martian surface environments (i.e., dust, CO_2 atmosphere). Tanks of high-energy propellant fluids, stored in their most efficient state, as low-pressure subcritical cryogenic fluids are susceptible to fluid loss through environmental heating. Novel concepts are being solicited to significantly reduce the heat conduction through tank supports and penetrations and reduce solar radiation losses with insulating materials or by intercepting shields. The ability to transfer cryogenic liquids in nominal, reduced and low gravity conditions from storage vessels or production facilities to user tankage is also critical. Cryogenic fluids are used for life support, propulsion, and power systems. Innovations in the following areas are needed:

- Lightweight, low thermal conductivity cryogenic tank strut and support concepts.
- Low thermal conductivity cryogenic tank penetrations, i.e., instrumentation feed-throughs, feedlines, vent lines.
- Lightweight, insulating thermal protection schemes.
- Robust insulation concepts for multiple launch/landing and ambient/vacuum pressure cycles.
- Devices for vapor-free acquisition of cryogenic liquids.
- Small, low power, lightweight (2 liter/minute) liquid oxygen transfer pumps.
- Tank pressure control (e.g., thermodynamic vent) and/or integrated tank boiloff control and product liquefaction technologies.
- Lightweight mechanical fittings and flexhoses with low heat leak.
- Autonomous cryogenic disconnects and couplings.
- Flowmeters and densitometers for measurement of densified, multi-phase cryogens at flow rates of 1.4 to 5.6 liters per second.
- Instrumentation for monitoring cryogens in low gravity including mass quantity gauging, liquid-vapor sensing and free surface imaging.

Cryogenic Pumping Systems without cryogenic seals. As an example, magnetically coupled pumps that can handle Liquefied Natural Gas (LNG), Liquid Oxygen (LO_2) or Liquid Hydrogen (LH_2). Magnetically coupled pumps eliminate one of the significant leak potentials in today's ground systems.

Cryogenic Quick Disconnects are particulate sensitive. Mating these disconnects remotely raises concern of seal damage and subsequent leaks at cryogenic temperatures. QDs in all sizes (0.25 to 10.0 inch diameter) are needed for future exploration missions and future launch vehicles.

Cryogenic Couplings are also particulate and scratch sensitive. Development of robust sealing couplings that are compatible with cryogenic temperatures and Liquid Oxygen compatible are also needed for future exploration missions and future launch vehicles. Diameters of 0.25 to 10.0 inches.

09 Achieve Routine Space Travel

NASA’s Human Space Flight Program seeks to open the space frontier by exploring, using and enabling its development, and to expand the human experience into the far reaches of space through the attainment of safe, reliable, low cost transportation. NASA seeks technologies to support the development of sensors and instrumentation systems, including ecological, environmental, and weather measurement technologies, for use in ground processing, launch, and landing of space vehicles and payloads. NASA seeks innovative technologies to prevent, detect, and retard corrosion of ground processing equipment and facilities. NASA also seeks innovative industrial engineering concepts, methodologies, and processes that will enable a more cost-effective and efficient hardware processing schedule.

09.01 Environmental and Ecological Technologies
Lead Center: KSC
Participating Center(s): none

Proposals are solicited for innovative and commercially viable technologies in environmental management, environmental and ecological monitoring, life sciences flight payloads and laboratory functions. Innovative technologies are needed that will improve the capability to collect and analyze environmental and ecological data. Of particular emphasis is the development of systems to monitor ecological parameters, biological organisms and environmental conditions remotely over long periods of time under field and controlled chamber conditions. Techniques to significantly improve and automate data management capabilities are required, especially those that incorporate geographical information system technologies for environmental and ecological monitoring and selected growth chamber data. Innovative remediation technologies are also important, particularly methods that minimize the impact to surrounding lands and facilities. Specific areas of emphasis are:

- Use of Global Positioning System (GPS) or other remote sensing technology in groundtruthing GIS data sets and automating data collection and analyses.
- Development of models for estimating wildlife populations and performing environmental impact predictions.
- Remediation technologies for chemical and petroleum soil and ground water contamination including in-situ methods and portable systems.
- Expert control systems for environmental chambers.
- Control technologies for cost-effective waste minimization and/or reuse of KSC industrial waste.
- Alternative technologies for monitoring microbial functionality in groundwater remediation systems and prototype bioregenerative life support subsystems.
- New and innovative light sources which have higher electrical conversion efficiencies and high photosynthetic spectral efficiencies are needed to meet the requirements of the bioregenerative life support systems on future, long-duration space missions.

09.02 Spaceport Instrumentation and Meteorological Technologies
Lead Center: KSC
Participating Center(s): none

This subtopic focuses on the development of sensors, transducers, instrumentation systems and meteorological technologies uniquely suited to and used for ground processing, launch, and landing of space vehicles and payloads. This subtopic also focuses on sensors, transducers and instrumentation systems uniquely suited for instrumentation test beds to be characterized as payloads on Space Shuttle or other future space vehicle flights as well as ground based. These test beds will be used to develop Integrated Vehicle Health Management System technologies with potential applications on future space systems. Specifically, this solicitation subtopic includes:

Small Mass Spectrometers
Smart, small, lightweight, rugged, inexpensive, automated mass spectrometer systems, or other technology capable of measuring one to one million parts per million of the following gases: Hydrogen, helium, nitrogen, oxygen, and argon. These instruments will be used on and around space launch vehicles for leak detection during ground processing, test firings, prelaunch propellant loading, launch, ascent, and descent (post reentry). The primary improvements in technology and performance are size and weight reduction and cost reduction. The target cost of operational versions of this instrument is $10,000-$25,000. Each instrument will be dedicated to a single sample line and shall report gas concentration and system health status continuously. Additional instrument performance goals are as follows:

- Desired accuracy: Plus or minus ten parts per million, or 5% of reading, whichever error is greater.
- Mass resolution: The instrument should be capable of meeting the desired accuracy goals for hydrogen in the presence of 100% helium, and for oxygen in the presence of 100% nitrogen.
- Size: Two cubic feet volume or smaller.
- Weight: 25 pounds or less.

- Ruggedness: Should withstand 18 gravities of vibration for 10 seconds.
- Automation: Within 5 minutes of application of 28 volt DC power, the instrument should power up to operational status, perform and continually transmit system health checks, and begin analysis.
- Stability: The instrument should maintain required accuracy for 12 hours either through inherent stability, or internal calibration. If this is not achievable, external zero, span and test gas can be supplied.
- Sampling: Should be capable of drawing samples through up to 400 feet of 0.18 inch inner diameter tubing.
- Current launch sites utilize a centralized-mass spectrometer system (commercial technology) which sequentially monitors multiple sample lines. The instruments are large and heavy, and must therefore be installed hundreds of feet from potential leak sites to protect the instrument from launch vibration, deluge water, rocket exhaust, etc. Response to potential leaks is delayed by the necessity to transport the samples long distances (200-400 feet) as well as time-multiplexing between multiple sample lines. While small and rugged mass analyzers have been developed for space flight experiments and payloads, they are typically too expensive to build (up to one million dollars) to meet spaceport instrumentation needs. Rather than one large expensive, time-shared mass spectrometer, NASA needs small inexpensive instruments that can be located very near leak sources, and dedicated to a single sample Line. This is analogous to a business converting from a mainframe computer to distributed desktop PC's.

Hydrazine Sensors
Develop and demonstrate either or both, portable direct-reading sensors and/or area monitors that can rapidly and more accurately detect hydrazine and monomethyl hydrazine. Both shall be capable of measuring at least 1 to 1000 ppb within 30 seconds to achieve 90% of final reading, and both shall be accurate (3 sigma noise) to the greater error of +/- 2 ppb or 10% of reading. The area monitor shall be capable of drawing adequate air samples and shall provide full accuracy monitoring from multiple remote sites, each at a distance of up to 100 feet from the central area monitor function. This performance for both shall be possible in 0-50 degree C air having Subtopic ambient humidity ranges. The sensor shall not give a hydrazine indication above 10 PPB in response to other common chemicals, such as hydrocarbons or ammonia, at interference levels of twice their allowable time weighted average (TWA). Both shall require 15 minutes or less warm-up time to reach full accuracy. Both shall operate from 3-6 months without requiring either calibration or maintenance. The current capability is within 2 minutes for area monitors and within 6 minutes for sensors, to achieve 90% of final reading, measuring 1 to 1000 ppb accurate (3 sigma noise) to the greater error of +/- 2 ppb or 15% of reading.

Remote Sensing of Electric Fields Aloft
An operationally viable, real-time method is required to measure the spatial distribution of the intensity of electric fields in and around clouds in the vicinity of the launch site near the time of launch. Remote sensing techniques are required. High reliability, high probability of detection and low false alarm rate is essential. Cost is a significant consideration. It is important to know the electric fields in warm clouds as well as near clouds in clear air. Also, a reliable method of assuring a detached thunderstorm anvil or thick stratus deck is charge-free is highly desired. The threat of adverse weather is a major cause of delay to launch, landing and ground operations. Lightning triggered by launch vehicles as they ascend is of special concern because current technology is inadequate to observe the conditions conducive to triggered lightning. No remote sensing capability currently exists to directly measure electric fields aloft. Techniques relying exclusively on surface field mill or conventional radar observations are known to be inadequate. Techniques such as dual-polarization radar are of limited value since they rely on the presence of ice in the clouds. Techniques, which pose potential risks to personnel or equipment, are not operationally viable.

Space Flight Test Bed Data Acquisition, Processing and Recording Units
Microelectronic, lightweight and rugged data acquisition, processing and recording units suitable for incorporation into space flight test beds. Must operate in vacuum conditions with no external cooling provisions. Must be modular and reconfigurable for reuse on different missions. Require up to 32 channels of 16-bit data acquisition with real-time digital signal processing (DSP) on every channel. Shall be powered using 28 VDC power supply. Environment: Vibration to 20gRMS, shock 40g for 11ms, operating temperature range at baseplate -40 to +70 degrees C, electromagnetic compatibility per MIL-STD-461C. shall provide for communication in a variety of protocols such as RS232, RS485, 10baseT and 10base100, Radio Frequency, and FDDI. An assortment of

advanced sensors will provide inputs to these units including smart sensors with RS485, thermocouples, RTDs, strain gauges and pressure transducers; all with various input voltage ranges from +/- 12.5 mV to +/- 10.0 V. Measurement accuracy shall be +/- 0.5% of full range. Experimental data acquisition systems, and current communications protocols, less the data processing capabilities, have been developed for Programs such as X-33 by Lockheed Martin Sanders and for future programs by Jet Propulsion Laboratory.

Space Flight Test Bed Micro Sensors
Micro sensors, lightweight, low power, non-intrusive for use on space flight test beds to detect CO, CO_2, O_2, O_3, CH_4, He and electrical current. Applications intended include CO, CO_2, O_2 and O_3 for Mars ground systems; and CH_4 for hydrocarbon based rocket engines for leak detection on ground and in flight. Also intended are He for launch vehicle pneumatic systems leak detection on ground and in flight, electrical current sensors for non-intrusive monitoring of electrical valves, and electromechanical actuators on ground and in flight.

- Range: CO, 25-75%; CO_2, 25-75%; CO_2, 80-100%; O_2, 80-100%; O_2, 0-100%; O_3, 50-10000ppm; CH_4, 50-10000ppm; He, 10-150scim; and electrical current, 0-3A.
- Accuracy: CO, +/- 0.5% full range; CO_2, +/- 0.5% full range; O_2, +/- 0.5% full range; O_3, +/- 10ppm full range; CH_4, +/- 10ppm full range; He, +/- 0.10scim full range; and electrical current, +/- 30mA full range.
- Response Time: CO, 10s; CO_2, 10s; O_2, 10s; O3, 10s; CH_4, 10s; He, 0.1s; and electrical current, 0.1ms.
- Environment: The devices shall survive vibration to 20gRMS and shock to 40g for 11ms.
- The operating temperature ranges shall be: CO, (25-75%) 500 to 750 degrees C; CO_2, (25-75%) 500 to 750 degrees C.
- Other ranges include: CO_2, (80-100%) 200 to 400 degrees K; O_2, (80-100%) 500 to 750 degrees C; O_2, (0-100%) 200 to 400 degrees K; O_3, (50-10000ppm) 200 to 400 degrees K. Also required are CH_4, He, and electrical current at temperatures from 75 to 175 degrees F.

Also required is electromagnetic compatibility per MIL-STD-461C. Similar devices exist for ground application but are lacking in capability to perform in a vacuum or Mars environment. Also, devices with accuracy near the 100% have not been found.

09.03 Process/Industrial Engineering Technologies
Lead Center: KSC
Participating Center(s): ARC, JSC

Spacecraft launch and payload processing systems have many unique aspects which require development of innovative process or industrial engineering (IE) technologies in order to obtain the substantial benefits derived from applying IE principles in other organizations. Process/Industrial Engineering is a technical discipline devoted to the science of process improvement and optimization of operational phases of complex systems. The Space Shuttle is NASA’s first major program with a long-term operational phase. All major current and potential future human space flight programs (the International Space Station, X-vehicles, and Mars missions) are also projected to have lengthy operational phases. Payload processing activities are also emphasizing repeatable processes and improved customer satisfaction. Therefore, the strategic importance of IE technologies to NASA is rapidly increasing.

Advanced spaceport technologies for designing, improving, and managing processes are needed to support spacecraft ground processing at KSC. Process/Industrial Engineering proposals should address the generic challenges of "doing more with less" and delivering safer, better, faster, and cheaper products/services. Proposals should also identify potential applications for enhancing the operational phases of new NASA programs and aviation depot maintenance processes.

Proposals may address the development of new concepts, methodologies, processes, and/or software support systems which advance the state-of-the-art in one or any combination of the following general areas of interest: operations research; process simulation modeling; statistical process control; experimental design; planning and scheduling systems; project management risk analysis; decision analysis; cost-benefit analysis; task/work methods analysis; work measurement; human factors engineering; ergonomics; facility layout/design; performance metrics; management information systems; and benchmarking.

Specific interests for the 1999 solicitation include, but are not limited to, those listed below:

- Advanced or automated task/methods analysis and procedure design techniques to enable effective implementation of advanced software and hardware systems in spacecraft test and checkout operations.
- Development of computer-based training for writing human-centered procedures. Development of evaluation and testing methods and metrics for procedure re-design.
- Advanced tools to measure and improve human-computer interaction with consoles and portable data collection devices.
- Advanced operations scheduling technologies which will improve support of vehicle and payload processing by supporting reduced cycle time, reduced resource requirements, more robust schedules, reduced user input/intervention, near real-time feedback of process/task completion, enhanced applicability to other domains and to new vehicles, and more explicit knowledge representation of the process.
- Tools and methods for integrating knowledge management into the technical, administrative, and business processes of a very large and highly technical engineering enterprise, from the strategic planning level to daily operations. The knowledge management program should include the following four elements: (1) capture: acquisition of critical knowledge in a form which can be efficiently retained, maintained, applied, and accessed; (2) maintenance: training new personnel on best practices learned through the experience of their predecessors, and updating the knowledge base as new knowledge is gained through research and development, collaboration, and benchmarking; (3) application: improving and expediting current processes and practices; and (4) distribution: providing access to the captured knowledge to multiple users, on- and off-site, in a reliable, efficient, and effective manner.
- Knowledge based tools and methods for providing highly effective just-in-time task level training in the operational environment. Development of augmented-reality situation displays for training and online information access.
- Advanced tools for assessing flight rate capacity and critical paths based on optimal allocation of hardware, software and human resources.
- Advanced operations research, decision analysis, and human factors engineering tools for optimizing utilization of scarce resources and minimizing the potential for human error during aircraft/reusable spacecraft (Shuttle and X-vehicles) maintenance activities.
- Innovative tools and proactive human factors methodologies, such as pre-task briefings, effective communication mechanisms, work observations, and peer evaluations, designed to reinforce desired jobsite behaviors and reduce human error related incidents.
- Advanced statistical quality control techniques for ensuring high quality, affordable manufacturing and maintenance of unique space hardware supporting human exploration and development of space.
- Advanced data analysis, mining, and warehousing tools to assist in the development and maintenance of metrics supporting performance-based contracting and process improvement activities. Structured approaches for relating process-level and organization-level metrics.
- Advanced technologies supporting workforce modeling in a technical environment.
- Tools to identify the parameters needed to quantify logistics mass and volume required to support a human Mars, lunar, or asteroid mission. Parameters include, but are not limited to, spares, tools, test equipment, maintenance consumables, and crew food and water. Tools should identify the typical system, subsystem, and line replaceable unit failure rates, mass, and volume characteristics to be used as input parameters for estimating logistics requirements until mission specific hardware data is available. Develop a model that utilizes these parameters to estimate logistics mass and volume requirements for a specific mission and then optimizes the spares mix based on cost, mass, volume, or system availability once the detailed mission specific hardware data set is available.
- An automated configuration management tool for virtual models and process simulations running at multiple locations to allow software developers to track various configurations. The tool should provide automatic stamping of simulations with the individual model characteristics and the date for each simulation to enable analysis, replication, and comparison.

- Develop concepts for fabricating parts from raw materials or recycled parts on Mars. Study availability of raw materials at the landing site of current or future programs and availability of materials from depleted systems or carried along in the complement of mission stores. Define a candidate list of parts that could be manufactured from available materials en-route or at the landing site. Utilize commonality of hardware to facilitate interchangeability of parts and limit the number of unique parts. Decide which types of raw materials to carry along on a mission to complement the raw materials at the destination. Study types of devices and systems needed for manufacturing. Develop techniques for stowage, transportation, and utilization of space-borne manufacturing equipment.
- Advanced operations process modeling, simulation, verification and validation technologies for cost-effective evaluation of the impacts of proposed changes to operational processes and procedures. Tools for rapidly assessing cost, schedule, and technical risks of proposed Shuttle hardware/software upgrades and process changes.
- Automated, advanced statistical quality control techniques that can be applied to data generated by space vehicle health monitoring systems. Non-intrusive automated health monitoring and exception reporting of ground systems. Automated resource and process scheduling using systems health monitoring data.

09.04 Spaceport Cryogenics Technologies
Lead Center: KSC
Participating Center(s): none

Advanced technologies are being solicited for cryogenic propellant systems for storage, transfer and control, and servicing to improve operational efficiency and reliability, and enable reliable autonomous loading and detanking operations. A key part of making cryogenic propellant servicing systems more efficient is how well they are integrated, physically and operationally, with their related subsystems and systems. Technologies that take into account the total energy balance of the launch facility must be given prime consideration. New and innovative techniques in technology areas such as connector materials, seal configurations, alignment and latching mechanisms, and autonomous operations that will enable reliable, verifiable, efficient, and repeatable system operations are desired for earth-based and low-gravity (Mars and lunar) launch facilities. Specific areas of interest include:

- Leak-proof compliant cryogenic connectors that can be reliably mated, demated, and remated under high misalignment conditions (25-30 degrees for connectors 1-inch and larger). Smaller connectors (1/4-inch to 1-inch) that require a low connecting force (for Mars applications) are critical. Reconnect issues that must be resolved include thermal (potential icing), sealing (surface damage due to environmental contamination), and cleanliness (potentially imposed by wind, etc.).
- Propellant servicing mechanisms including umbilical alignment, latching, and release mechanisms which provide reliable and verifiable single and multiple mating, and enable autonomous loading operations. Integrated alignment and connection methods are desirable. Innovative latching technologies such as shape memory alloy applications and technologies that allow for maximum preload with minimal application loading are also desirable.
- Recovery and storage system for gaseous hydrogen as vented during vehicle loading and drainback operations. Gaseous helium recovery (from hydrogen stream) is also required. Small-scale technology demonstration is desired for Phase I, followed by large-scale system demonstration for Phase II. System must have bypass capability to preclude potential launch impact in the event of a subsystem anomaly. Desired outcome for Phase III is a full-scale operational system for use with the Shuttle Transportation System or other full-scale vehicle such as VentureStar.

09.05 In-Situ Support Equipment for Surface Operations
Lead Center: KSC
Participating Center(s): none

Current surface operations concepts for Mars exploration include several surface systems that must be deployed and operated for significant periods of time before the crew arrives. These systems include the power plant, the In-Situ Resource Utilization (ISRU) plant, and associated systems (e.g., thermal control system). A high degree of automation is associated with these activities including preparation of surface sites, deployment of potentially large and complex systems, inspection of these systems as they are operated, and performance of routine maintenance and repair as required. Methodologies and technologies are solicited for automated and manual In-Situ support mechanisms that will enable the deployment and operation of all surface systems prior to and after the arrival of the crew. All methodologies and technologies shall also demonstrate commercial Earth-based and near Earth-based applications and have multiple function or operational capabilities. The following are the areas of interest, but are not limited to:

- Autonomous techniques to perform periodic inspections, periodic maintenance and repairs on equipment and flight hardware sent to Mars prior to crew arrival (e.g., fluids servicing, non destructive testing, thermal protection system maintenance, cleaning operations, pipeline inspections).
- Autonomous/tele-operated techniques for self-deploying umbilical for connecting ISRU plant to power plant.
- Autonomous assembly concepts for constructing pre-deployed infrastructure.
- Autonomous/tele-operated soil moving concepts for building power plant protection berms and other surface preparations.
- Mechanisms for repositioning mobile support systems on the Mars surface.
- Techniques for accessing high locations on vehicles for maintenance or inspection purposes.
- Techniques to minimize ascent vehicle launch blast damage to infrastructure at Mars launch site.

10 Enrich Life on Earth Through People Living and Working in Space

By its nature, the exploration and development of Space expands our knowledge and fosters technologies that have great potential benefit on Earth. The HEDS enterprise will be alert to and communicate the early medical, educational, economic, and social benefits from its programs. The objectives of this topic include promoting knowledge and technologies that promise to enhance our health and quality of life; broadening and strengthen our nation's achievements in science, math, and engineering; involve our nation's citizens in the adventure of exploring space; and joining other nations in the international exploration and settlement of space.

10.01 Commercial Microgravity Research and Outreach
Lead Center: MSFC
Participating Center(s): none

In accordance with the Space Act, as amended, to "seek and encourage to the maximum extent possible the fullest commercial use of space," NASA facilitates the use of space for commercial products and services. The products may utilize information from in-space activities to enhance an Earth-based effort, or may require in-space manufacturing. This subtopic has two goals. First, the commercial demonstration of pivotal technologies or processes; second, the development of associated infrastructure equipment for commercial experimentation and operations in space, or the transfer of these technologies to industry in space or on Earth. Automated processes and hardware (robotics) which will reduce crew time are a priority. All agency activity in microgravity including those in life science and mircogravity sciences, which lead to commercial products and services, are of interest. Some specific areas for which proposals are sought include:

Cell System Biotechnology
Instrumentation to analyze cell reactor systems and characterize cell structure in micro-gravity in order to develop enhanced drug therapies that can also be applied to pharmaceutical development and commercialization.

Biomedical and Agricultural Instrumentation or techniques that exploit space-derived capabilities or data to support the commercial development of space by the agricultural, medical or pharmaceutical industry. This includes, in particular:

- Innovative techniques for dynamic control and cryogenic preservation of protein crystals.
- Innovations in preparation of protein crystals for x-ray diffraction experiments without the use of frangible materials.
- Physiological measurement in micro-g of bone growth and immune system in micro-g.
- Agricultural research, i.e., genetic engineering of plants using micro-g.
- Innovative research in plant-derived pharmaceuticals using micro-g.

Materials Science
- Applications using space-grown semiconductor crystals including epitaxially grown materials for commercial electronic devices. The applications will also attempt to use the knowledge of the space-grown material behavior to enhance ground processing of the materials to achieve equivalent performance of space-grown materials in electronic circuitry.
- Applications using space-grown optical electronic materials such as fluoride glasses and non-linear optical compounds for commercial optical electronic devices and to achieve equivalent performance of space-grown materials in ground processing.
- Innovations using non-linear optical material to be processed in space.
- Innovations for new space-processed glasses for optical electronic applications.

Microgravity Payloads
- Design/develop microgravity payloads for space station applications that lead to commercial products or services.
- Enabling commercial technologies that promote the human exploration and development of space.

Combustion Science
Innovative applications in combustion research that will lead to developing commercial products or improved processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Food Technology
Innovative applications of space research in food technology that will lead to developing commercial food products or improved food processes through the unique properties of space or through enhanced or innovative techniques on the ground.

Outreach
NASA wants to provide to the general public, schools and industry, access to its science and technology. To accomplish this aim, the ability to receive, process and display telemetry, view video from science sources, including the ISS, and talk to NASA about the science and operations is required.

There are many potential users for NASA services and data located throughout the U.S. There are four general types of users for NASA activities. The first type is the principle investigator who is responsible for the spacecraft, experiment and attendant science and commands the payload or experiment. The second type is the secondary investigator(s) who participate in analysis of the science and its control but does not send commands. The third type is the educational user from graduate students to secondary school students. These users will receive data either processed by the PI or unprocessed. The last type of user is the general public user who is interested in science that is being conducted. Public participation will generally be benign in that they will receive voice, video and processed data but generally will not be allowed to be interactive.

To conduct or be involved in general science activities including the ISS science operations a user will require various services from the Payload Operations Integration Center (POIC) located in Huntsville, Alabama, or other control centers located at various NASA facilities. These services are required to enable the experiment to be controlled using the inputs from various video sources, telemetry and the crew. Inputs allow the experimenter to send to their spacecraft or experiment commands to change various experiment operations. Before an experiment can get underway, an experimenter must participate in the payload planning process to schedule on board services like electricity, crew time and cryogenics. This planning process is integral to the entire payload operation and requires the PI or PI’s representatives to participate via voice or video teleconferencing.

To enable users to operate from their home base, whether it be their lab, office or home, these services (commensurate to the level of their operation) must be provided at their location at a reasonable cost for both the platform upon which these services will run and the communications required to get these services to the experimenter's location.

For this solicitation provide a system or systems based on commercial solutions to allow participation in NASA science programs down to the science and operational levels. Provide to the general public, access to NASA science activities and operations through low cost technologies. Provide access to and the ability to participate in science activities by secondary and college level students, and finally, provide access to institutions and organizations who promote the use of science and technologies, e.g., museums, space camps.

11 Advance Space Communications and Operations

For frequent, affordable, capable space missions in the 21st century, key technologies that contribute to lowering life-cycle costs and increasing scientific returns are required. This includes technologies, concepts, and advanced techniques for reliable telecommunication services, microelectronics, flight computing, autonomous spacecraft guidance, navigation, tracking and control, 'intelligent' and automated ground and flight systems, data transfer, handling and storage, high-speed data communications networks. For NASA’s use of commercial services, advanced techniques and products that support commercial LEO/MEO/GEO satellite networks are needed.

11.01 Flight/Ground System Autonomous Operations
Lead Center: JSC
Participating Center(s): none

Development of spacecraft with a high degree of onboard autonomy, possessing autonomous navigation and control, self-monitoring, and smart instruments will enhance the efficiency of upcoming NASA flights. The challenges include selective migration of operations functions to the spacecraft, new onboard software architecture and operating system concepts to integrate these functions, and new software design. NASA seeks innovations that demonstrate the following characteristics: spacecraft and instruments appearing as nodes on a network; similar ground and flight operating systems; spacecraft interfaces that appear the same to ground support systems; system operations requiring minimal hands-on effort; centralized anomaly resolution; and direct delivery of science data to users.

In the area of onboard autonomy, interests include:

- Guidance, navigation, and control.
- Planning, scheduling, and resource management.
- Onboard data management.
- Fault detection and recovery.
- Onboard software architectures and operating systems.
- Design, testing, and validation tools.

Innovations should use commercial standards for development, off-the-shelf hardware and software when possible, and have a high degree of commercialization potential.

Other areas of interest include:

- Multimedia for access and control of all mission-specific data and processes.
- Direct access to and control of instruments and their returned data by the investigators.

- Distributed intelligent agents for automation of spacecraft and ground operations functions.
- Advanced applications of expert system, model-based, and agent-based technologies in mission-operations automation.
- Internet-based and Java-based approaches to mission operations.
- Advanced data and information visualization techniques for mission.
- Reuse of mission operations software on NT platforms in addition to UNIX.
- Flexible plug-and-play architecture and standards.
- Plug-and-play commercial software components that execute operations functions.
- Techniques and tools for incorporating legacy applications into plug-and-play architectures.
- Techniques for electronic documentation, electronic process control, massive distributed databases, intelligent archiving and retrieval, data analysis and visualization and other advanced information technologies.
- Innovations for greater capacity high-speed data communication networks that are the result of increased data transfer and storage requirements.

8.3 EARTH SCIENCE

NASA's Earth Science Enterprise uses satellites and other tools to intensively study the Earth in an effort to expand our understanding of how natural processes affect us, and how we might be affecting them. Such studies will yield improved weather forecasts, tools for managing agriculture and forests, information for fishermen and local planners, and, eventually, the ability to predict how the climate will change in the future. Earth Science has three main components: a series of Earth-observing satellites, an advanced data system, and teams of scientists who will study the data. Key areas of study include clouds; water and energy cycles; oceans; the chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth. Working together with the nations of the world, Earth Science seeks to improve our knowledge of the Earth and to use that knowledge to the benefit of all humanity.

http://www.earth.nasa.gov

12 Earth Measurement Systems

NASA is fostering innovations that support implementation of the Earth Science (ES) program, an integrated international enterprise to study the Earth system. ES uses the unique perspective available from orbit to study land cover and land use changes, short and long term climate variability, natural hazards, and environmental changes. Additionally, ES uses in-situ and airborne measurements to complement those acquired from Earth orbit. The largest ground and data system ever undertaken will provide the facility for command and control of flight segments and for processing, distribution, storage, and archival of vast amounts of data.

This year's subtopics specifically do not include the in-situ stratospheric research, nor the non-laser and synthetic aperture radar system instrument development for remote ecosystem sensing. These are expected to be back on a rotating basis in future SBIR/STTR Solicitations.

12.01 Laser Remote Sensing Technology
Lead Center: GSFC
Participating Center(s): none

Laser sensors require substantial technology and sub-system improvement for airborne and space-based remote sensing of planetary surface topography, vegetation, clouds, aerosols, winds and wind shear, trace species, and sub-surface ocean layers; and for ground-based lidar systems and laser ranging systems that measure atmospheric backscatter, vegetation structure and composition, and pulse time-of-flight to laser transponders or reflectors on satellites. Innovations are required in the laser sources, detectors, optics, and electro-optics as well as in the overall efficiency, compactness, and reliability of the sensor. Our main goal is the development of a new generation of instrumentation for high-data-rate, low cost, autonomous operation. Technology requirements are driven by space flight and Unmanned Aeronautical Vehicle (UAV) lidar systems applications. To enable the implementation of Earth and Space Science applications, innovations are needed in the areas of new rugged, efficient, powerful lasers and tunable sources as well as rugged, agile, tunable filters, fast optical switches, and pointing systems. Specific technology challenges include:

- Lasers and lidar transmitters, with particular emphasis on: Pulsed Nd:YAG or Yb:YAG laser oscillators based on aluminum-free diode-pumping; solid-state laser technology that employs diode-pumping to achieve tunable and/or single frequency operation; compact and conductively cooled lasers. Particular wavelengths of interest include 355nm, 532nm, 1064nm, 946nm, 1-5 microns, 300-350nm, 800-860nm, 930-950nm, and 1500-1700nm. Emphasis on technologies that can provide high electrical-to-optical efficiency and long-life times for spaceborne applications. There is interest in both high pulse energy, low repetition rate systems and low pulse energy, high repetition rate systems.
- Lidar receivers and transceivers including technologies that are: large aperture, ultralight, scanning, high efficiency, aperture sharing, multiple view angles, narrow field-of-view, and narrowband filtering.
- Detectors with improved quantum efficiency, fast rise time, high speed, linear response, and low noise. Includes silicon avalanche photodiodes array detectors, microchannel plate photomultipliers, and photon counting detectors. Particular interest in single-element and array detectors combined with preamplifier circuitry in a single integrated circuit.
- Oceanic LIDAR systems or components in the 480-685nm wavelength region for remote sensing of sub-surface ocean layers and fluorescence.
- Filters for lidar measurements, including both solar blocking filters and high spectral resolution filters. Includes narrowband notch filters, high transmission narrow bandpass optical filters, and tunable filters for the near-UV through the near-IR wavelength region. Other areas of emphasis are: high spectral resolution, high throughput, out of band spectral blocking, frequency tunable, and frequency stabilized.
- Compact, power efficient, frequency reference with better than 1 part in 1014 stability and accuracy that is suitable for interplanetary missions.
- Signal detection and processing subsystems with fast recovery (less than 30microsec) from saturation.

- Laser techniques and component technology for measurement of the wind field and wind sheer in the lower atmosphere using direct-detection methods, with high accuracy and high range resolution. Eye safety is a consideration.
- Particular innovations for laser components include: high power semiconductor optical amplifiers for the near-IR; high-power fiber optic amplifiers for the near-IR; efficient, tunable fiber optic lasers; efficient and rugged harmonic generating crystals for both high- and low power lasers; and fiber optic oscillator/amplifier transmitters for single frequency and single transverse mode.
- Electrically efficient and rugged lasers in the 300-350 nm range.
- Efficient pulsed and CW lasers in the 1-5 micron region.

12.02 Remote Sensing Technology for Coastal Research
Lead Center: SSC
Participating Center(s): none

The coastal region is comprised of ecosystems marked by frequent change and widely fluctuating transitional boundaries of land and water. Remote sensing technology is needed to better identify and delineate important coastal environmental phenomena and to characterize their temporal and spatial dynamics. This includes imaging in the solar-reflected spectral region over a range of temporal and spatial scales. Emerging applications will study the complexity and dynamics of the zone extending several kilometers seaward or inland of the shoreline. Significant remote sensing technologies exist currently that have the ability to characterize:

- Both surface and subsurface water variables (e.g., temperature, salinity, suspended materials) and their changes with depth.
- Vegetation changes occurring on small spatial scales or for which the spectral response is influenced by changing water level.
- Natural hazards (e.g., hurricanes, sea level rise) and man-induced pressures on land cover and land use change in near shore areas.
- Subsurface soil and sediment properties and their changes with depth in environments covered by vegetation or water.

Efforts to integrate multiple sensors and/or supporting instrumentation are needed. Specific technological areas of focus include the following:

- High Spatial Resolution, Hyperspectral/Thermal Airborne and Ground-Based Sensor Technology:
  - Broad emphasis on imagery of dry land and wetland vegetation, and water targets within the incident solar (ca. 400-2,500 nm) and emitted thermal (8-14 mm) spectra.
  - Ground pixel resolution of 1 square meter or better while maintaining a scan swath width of 0.5 km or more for airborne systems.
  - Image resolution of 640 by 512 pixels or better for ground-based instruments.
  - Hyperspectral bands of: 10 nm or better spectral resolution to span the 400 nm-NIR range; 20 nm or better resolution to span the NIR-2,500 nm range.
  - One or more bands in the 8-14 mm range.
  - Co-registration of all channels in a data cube that contains GPS coordinates for target location.
  - Channel selectivity based on application.
  - Radiometric calibration for each channel.
- High Resolution, Low Frequency, Subsurface-Penetrating Sensor Technology:
  - Emphasis on measurement for a stratified depth profile in soils, peatlands, wetlands, and shallow marine environments.
  - Examples of variables of interest for characterization: organic/mineral sediment type; inundation/wetness condition; presence of archeological and other anomalies (e.g., mineral deposits, pipelines); physicochemical water properties (e.g., salinity, dissolved compounds/pollutants).
  - Low frequency range (100 Hz - 500 MHz).
  - Spatial resolution: vertical <2m; lateral <10m.

  - Depth penetration: desired range of 1m minimum - 30m maximum (including water depth).
  - Incorporate capability for good geopositioning.
  - Desirable to incorporate innovative, independent technologies to measure variables (e.g., temperature) for improved inversion data analyses.
- Moderate Resolution Hyperspectral Sensor Technology from Earth Orbit: Spectral sampling at 10nm bandwidth over 0.4-2.5 mm with high signal to noise ratio over 5-80% albedo.
- Spatial resolution and coverage of ~30km swath at 30m GSD from ~490km altitude.
- Emphasis on spectral and radiometric calibration and spatial/spectral co-registration of the data cube to enable advanced surface retrievals and compensation of atmospheric/scattering effects.
- Demonstrations of interest include: size/mass reductions in integrated camera/spectrometer systems utilizing modular architectures, high read rate VIS/NIR and SWIR focal planes with reduced power/cooling needs; integrated sensor system electronics; onboard processing and data reduction tailored to data type and application.

12.03 Lidar Systems for Atmospheric Measurements
Lead Center: LaRC
Participating Center(s): JPL, MSFC

Innovative developments are needed in lidar technology for the remote measurement of atmospheric aerosols, clouds, molecular species (ozone, water vapor, carbon monoxide, carbon dioxide, methane, and nitrous oxide) and meteorological parameters (density, pressure, temperature, and wind profiles). Specifically, technologies for expanding the measurement capabilities of current airborne lidar systems and for the next generation of spaceborne and Unmanned Aeronautical Vehicle (UAV) lidar systems are sought. Technology innovations may include lidar components, subsystems, and complete systems and may address reduced weight or power or increased energy efficiency, reliability, or autonomous operation.

For Atmospheric Constituent Measurements

- Solid-state laser technology for tunable and/or fixed frequency, high-energy (>500 mJ at more than 10 Hz) pulsed lasers for spaceborne applications. This includes solid-state laser materials compatible with diode pumping and high efficiency (>2.5% wallplug) and new or improved optical materials for high efficiency frequency conversion. Of prime interest are long-lifetime, low weight and volume materials and technologies applicable to highly efficient, conductively cooled lasers operating in the 0.28-0.32, 0.47-0.54, 0.7-1.1, and 1.5-2.8 micron regions; also interested in the 3.2-4.7 micron region. Also needed are single-mode, line-narrowed, compact sources for injection seeding in the 0.7-1.1 and 0.28-0.32 micron regions and high reliability, high efficiency, conductively cooled diode arrays operating in wavelength regions for pumping solid-state lasers.
- Lidar receiver technology for large (> 3m^2), lightweight collection apertures having multiple-wavelength operation from UV to near IR are needed. Inherent spectral selection/dispersion and high peak transmission (50-80 %), electromagnetically tuned, narrow bandwidth (10-100 picometers) filtering are desirable. Small- and large-angle scanning (up to 3 degrees and 30-60 degrees off nadir, respectively) of 0.5-meter and 1.0-meter lidar systems are needed for space. Low mass and few to no moving parts.
- Signal detection and processing subsystems with quick recovery (less than 3 microseconds) from saturation and high-speed, high-quantum efficiency (30-80 %) detectors with low-noise and good linearity are needed for lidar operation over large dynamic ranges.
- For UAV applications, compact, high repetition rate, narrow linewidth laser transmitter systems are needed that produce energies from micro- to milliJoules (30 to 50 mJ) per pulse. Laser energies of more than 100 mJ at 30-1000 Hz in the UV and more than 200 mJ at 10-20 Hz in the 355, 940, and 1064 nm region are needed.
- Optical phased array scanning concepts for programmable beam pointing with high transmission (>90%) and angular deflection capability >20 degrees. Aperture diameters from 2cm to 1m are of interest and preservation of beam quality is a primary requirement.
- Compact tunable pulsed and cw laser sources in the 6-8 micron wavelength region with moderate output capability (10 mJ pulsed – 10 mW cw).

For Coherent Wind Measurements

- Low mass, compact optics for deflecting a circularly polarized laser beam for a conical scan. Diameters of 5 cm to 1 m with an immediate need of up to 50 cm. Preservation of laser beam quality is required.
- Technology for autonomous operation and alignment maintenance of coherent lidar systems.
- Fast (few tens of microseconds) lag-angle compensation optics technology for precise, reliable steering of the optical axis of a space-based Doppler lidar.
- Single-element and array detectors having high bandwidth, high quantum efficiencies over the entire bandwidth, linearity, and minimum cooling requirements. Also, an optical detector combined with a preamplifier in a single integrated circuit, with combined bandwidth up to several GHz.
- Pulsed, eyesafe laser technology having technical path leading to simultaneous characteristics of >2J energy, >12 Hz PRF, < 500 W laser power requirement when pulsing, < 2 microsec duration, < 1 m/s equivalent pulse spectrum, < 1.3 m^2 beam quality, intermittent operation with periods of 1-10 minutes and duty cycle around 20 % and minimum "off" power draw and minimum time to restability, and which shows potential for 7-year lifetime in space environment.
- Diode-laser arrays operating near 0.79 micrometers having pulse lengths >1.0 ms, energy densities >1.3 J/cm^2, duty cycle >0.20 and narrow beam divergence.
- High efficiency methods for concentrating the emissions from nominal 1.0 cm square arrays to 4.0 mm diameter spot sizes.
- Tunable single-mode semiconductor lasers or other compact, single frequency sources for use as injection seeders and/or local oscillators, with linewidths 0.1-0.2 MHz operating in the 1.8-2.2 micron and 3.0-3.5 micron regions.
- Concepts for compact ultrabroadband (up to 50%) coherent optical generation schemes in the visible to eyesafe near-infrared spectral region.

12.04 Passive Optical Systems and In-Situ Analytical Instrumentation
Lead Center: GSFC
Participating Center(s): JPL

Passive Optical Systems

Proposals are sought for the development of innovative technology for measuring the atmosphere and Earth surface using passive optical techniques to increase our understanding of the interacting physical, chemical and biological processes that form the complex Earth system. The wavelengths of interest include IR, visible and ultraviolet bands. Technology innovations may include components, subsystems, and complete systems and should address reduced size, weight or power, improved reliability and lower cost. The innovations should expand the capabilities of airborne systems (manned and unmanned) and the next generation spaceborne systems. Specific needs include:

- Innovative instrument architectures that provide significant reductions in the end-to-end implementation. For example, spectrometers (UV, visible, shortwave, thermal IR) with a built-in programmable band aggregation capability such that, by uploading simple commands, any combination of disjoint or contiguous bands can be output in compressed form, ranging from a single band to the complete measured spectrum; the goal is a unified design with the band aggregation capability built into the hardware and chip set, not a computer tacked onto the back end of a spectrometer. The capability for near real-time processing, atmospheric correction, and geolocation and geometric correction of digital image data are also desired for surface observations.
- Designs and component technologies relating to improved sensors for observation of cloud and aerosol in the Earth's atmosphere. Examples of instruments include multispectral imaging radiometers, flux radiometers and high resolution spectrometers for wavelengths from the UV far IR. Innovative measurement concepts or advances leading to smaller and lower cost instruments will be considered. Technical approaches should include application of uncooled infrared detectors, non-mechanical choppers, calibration methods and tuned filters.
- Optical imager technologies that will enable lightweight, low cost large aperture optical systems optics for a variety of land, ocean, and atmospheric observations through the elimination of conventional telescopes and focal planes in space-based imagers. For example, planar-phased arrays or multispectral imagers based on

holographic and/or diffractive optics. Instruments should have performance specifications comparable to or better than current imagers such as MODIS or ALOS.

- Tunable acousto-optical filters that can cover the wavelength range 300-600 nm, at 1 nm or better spectral resolution.
- Wedge filters suitable for space application that can cover the nitrogen dioxide absorption bands (420-460 nm) at better than 1 nm resolution, and for hyperspectral digital image data, particularly with respect to spanning the visible, near-infrared, and shortwave infrared portions of the electromagnetic spectrum and with respect to acquiring data of moderate spatial resolution (circa 20 m).
- 4 K x 4K and larger detector arrays sensitive in near UV (300-400 nm) and Near IR (1-3 micron) with large (> 1 million electrons) well depth.
- Fast, 1 meter diameter lightweight telescope for space application with minimal distortion in the 0.3 - 3 micron wavelength range.
- Ultra-stable remote sensor calibration techniques for long term trend determination in space instruments.
- Development of systems capable of off-nadir pointing for the acquisition of multi-angle data, the acquisition of stereo pairs, scanning and tilting to remove sun reflection off the ocean, and the frequent imaging of rapidly changing events from orbit. Very low mass, power and high speed and flexibility are desired.

In-Situ Analytical Instrumentation

Advanced mass spectrometer systems and components for use in atmospheric composition measurements of Earth and planetary atmospheres, and for the next generation of miniaturized, solenoid latching valves used in gas sample inlet systems of gas chromatograph/mass spectrometers. Technology innovations should produce a valve, which will be smaller and lighter than those used on these previous missions while maintaining their high performance specifications.

- Mass spectrometer needs include: Advanced technology for a time-of-flight system with: (1) a total weight of less than 1kg; (2) a large dynamic range of at least 1E8; (3) a mass range of 1 to 2000 amu with unit resolution throughout the entire range; and (4) innovative ionization techniques that will improve the sensitivity by an order of magnitude over current mass spectrometer ion sources.
- Requirements for a miniaturized valve include: The valve must be: (1) latching; (2) bakeable to 300C; (3) case leak and seat leak rate less than 1E-10 atm.cc/sec; (4) less than 5 grams and less than 20 mm long x 13 mm diameter; and (5) areas exposed to the incoming gas stream shall be free of organic and hydrocarbon contamination and shall typically be made of materials such as inconel and titanium.

In-Situ Measurement and Data Acquisition Systems

Systems to supply key in-situ information on the upper ocean and lower atmosphere; of interest are:

- Small, lightweight instruments suitable for balloon, kite, or small remotely piloted aircraft for in-situ measurement of atmospheric trace gases and cloud/aerosol chemical, microphysical, and radiative properties (extinction, absorption, scattering phase function, and phase function asymmetry).
- High-sensitivity measurement of atmospheric trace gases; robust instrumentation for unattended operation in harsh environments.
- Low cost, lightweight, deployable sensors for in-situ and aircraft measurements of liquid and ice hydrometeors in cloud and precipitation systems.
- Systems for in-situ measurements of atmospheric electrical parameters including electric and magnetic fields, conductivity, and optical emissions.

Autonomous low cost instruments and data systems to measure surface and lower atmospheric parameters, including composition, soil moisture and pH, precipitation, temperature, incoming and upwelling spectral radiation, wind speed and humidity. Instruments should have power and data system compatibility with existing systems or standards.

Measurement and data acquisition systems to supply key in-situ information on the upper ocean and lower atmosphere: of interest are autonomous GPS-located ocean platforms to measure and transmit information as well as instrumentation for particular measurements, including underwater acoustic techniques for biological as well as ocean temperature applications. Data of interest includes temperature, salinity, chemical composition (especially nutrients and pollutants), momentum, light, humidity, precipitation, and biology. Similar sensor packages for use onboard ships while under way or for deployment on submersibles.

12.05 Measurement and Enhancement of Satellite Scientific Data Quality and Applicability
Lead Center: SSC
Participating Center(s): none

Proposals are sought for the development of advanced technologies to enhance the commercial application of the commercial remote sensing industry and enhance the commercial application of Earth science data. Focus areas are to provide tools for interpretation, visualization or analysis of remotely sensed data; and to provide qualitative and quantitative analysis tools and techniques for performance analysis of remotely sensed data. Areas of specific interest include:

- Visualization of multi-variate geospatial data including remotely sensed data from the following: 1) airborne and satellite platforms, vector data from public and private archives; 2) cartographic databases from public and private sources; 3) continuous surface data held as a raster data model; and 4) 3-D data held in a true 3-D raster model.
- Innovative approaches that contribute to the understanding of data through the display and visualization of some or all of the above data types including providing the linkages and user interface between the cartographic model and attribute databases.
- Innovative approaches for incorporation of GPS data into in-situ data collection operations with dynamic links to spatial databases, including environmental models.
- Data merge and fusion software for efficient production of commercial digital products.
- Data mining systems to allow content-based searches of ES databases and reduction of bandwidth transmission to essential-only data.
- Techniques to enhance performance of wide-area networks supporting highly distributed data production, archive, and access functions.
- Autonomous classification systems of high resolution digital data.
- Fusion of science data sets to correlate similar data sets from diverse spacecraft and aerial vehicles and provide unique, commercially useful information products.
- Innovative techniques for the validation of thermal and LIDAR imaging systems.
- Software to commercialize the digital topography and vegetation canopy data products that are obtained by airborne and space-based active optical sensors.
- Innovative techniques to automate quality assurance processes for science data products.
- Unique, innovative data reduction and analysis methodologies and algorithms, particularly for hyperspectral data sets.

12.06 Microwave Remote Sensing Technology
Lead Center: GSFC
Participating Center(s): none

Proposals are sought for the development of new techniques or systems for the following areas:

Techniques or Subsystems for the Detection and Removal of Radio Frequency Interference (RFI) in Microwave Radiometers

- The measurement of a microwave radiometer can be contaminated by RFI if a source with sufficient strength is radiating within the reception band of the radiometer. Even though microwave radiometers are supposed to be operating within protected bands, RFIs do happen from time to time. Electronic subsystems that can be incorporated into microwave radiometers to detect and remove RFIs are very useful in insuring data quality.

New Calibration Reference Source for Microwave Radiometers

- High emissivity (near block-body) surfaces are being used as onboard calibration targets for microwave radiometers, either airborne or spaceborne. NASA is seeking new design using noise-diode or other electronic devices as additional reference sources for onboard calibration.

Airborne Radars for Measuring Rain and Cloud

- Novel approaches for developing compact, lightweight airborne rain and cloud radars are sought. Areas such as antennas, RF sources, and data processing subsystems are of especial interest. Lightweight design is important to facilitate use aboard Unpiloted Airborne Vehicles (UAVs) for atmospheric science research purposes.

Ground-Wave Propagation System for Measuring Soil Moisture

- NASA is developing satellite systems that will use L-band microwave emission from the surface to measure soil moisture to a depth of ~ 10cm. A ground-based network of sensors capable of measuring areas at least 105 km2 with spatial resolution of 20 km will be needed to validate the space-borne measurements. Measurement of ground-wave propagation characteristics of radio signals from commercial sources may satisfy that need. Although absolute values of soil moisture are desirable, they are not required if the technique can be calibrated frequently at suitable sites. Cost per covered area, autonomous operation, anticipated accuracy and depth resolution of the soil moisture measurement will be considerations for selection. Reference: Recommendations and Reports of the CCIR, International Radio Consultative Committee, (1982), Vol. 5, Propagation in Non-Ionized Media, Geneva, pp. 59-62.
- Low cost, hand-held transceivers/display units capable of receiving only, transmitting only, and both receiving and transmitting satellite-relayed disaster-related warning or mitigation information broadcast over special frequencies allocated for emergency and weather use.

12.07 Earth Science Information Technology
Lead Center: GSFC
Participating Center(s): none

All NASA projects will face the daunting prospect of having to deal with databases of unprecedented size and complexity. We must develop techniques for electronic documentation, electronic process control, massive distributed databases, intelligent archiving and retrieval, and data analysis and visualization. NASA is soliciting technologies to perform a wide range of functions including:

- Innovative and efficient methods/algorithms/systems for warehousing scientific multi- and hyperspectral data and/or instrument data for automatic and user-directed mining/monitoring of meaningful trends, parameters, fluctuations, etc. to maximize scientific value of TB-sized data sets.
- Data viewing and real-time data browse, including fast, general purpose rendering tools for scientific applications.
- Innovative approaches to enable the fusion and interpretation of disparate data sources such as multi- and hyperspectral data and ancillary data sets.
- Intelligent autonomous mobile search agents to support science applications involving data available on the World Wide Web.
- Automated space-ground communication system: communications are established at system's ground stations upon request by overflying spacecraft that have data to transmit.
- The use of FPGA's to provide real-time products using hyperspectral instrument data from airborne platforms.
- Ultra-compact, hyperspectral imagers with co-registered bands (minimally covering the spectral range from 0.4 um to 1.1 um and a minimal spectral bandwidth of 1.5% of center wavelength) to support calibration and validation of Earth Science spacecraft missions.
- Exploration of innovative sensor technology such as the use of liquid crystal tunable filters (LCTF) and/or acousto-optical tunable filters (AOTF) operated by either RF or piezo-electronic exciters in the acquisition of remote sensing images.

- Automatic dynamic reconfiguration of UAV or satellite onboard data gathering instruments to make effective use of observing conditions, baseline image data priority scheme, history of observations, and limited onboard resources (e.g., data storage, communication bandwidth) while meeting mission objectives, such as matching choice of spectral bands dependent on features currently being overflown.
- Design and implement a virtual reality CAVE for scientific data visualization that is at least 1/20 the cost of current CAVE implementations (implementation of floor screen and head tracking optional).
- Low cost hardware and/or software units, subsystems, and interfaces that contribute to enabling HDTV data communications over digital packet or cell switched networks or HDTV data capture and/or display by desktop digital computers.

12.08 Science Payload Pointing, Space Platform Control and GPS Guidance
Lead Center: GSFC
Participating Center(s): none

A vigorous effort is needed to develop guidance, navigation and control methodologies, algorithms, sensors and actuator technologies to enable revolutionary Earth science. Exploiting new vantage points, developing new sensing strategies, and implementing system-wide techniques which promote agility, adaptability, evolvability, scalability, and affordability are characteristic of the technological challenges faced and representative of the significant leap beyond the current state-of-the-art required. Specific areas of research include:

- Advanced sensors, actuators, and components with new or enhanced capabilities and performance, as well as reduced cost, mass, power, volume, and reduced complexity for all spacecraft GN&C system elements. Additional emphasis is placed on improved stability, accuracy, and lower noise angles.
- Concepts for autonomous guidance of space transportation systems during atmospheric flight phases.
- Control theory, filtering techniques, processing advances, software architectures, and improved environmental models for attitude and trajectory determination and prediction. Filtering techniques and expert systems applications for near real-time trajectory determination and control. Methods for in-flight attitude sensor alignment and transfer function calibration.
- Rigid and flexible body control methods that are robust to parametric uncertainty and modeling error.
- Innovative testbed development capabilities and computer-aided engineering and design tools with parallel algorithms for analysis and development of GN&C systems.
- Autonomous performance of ground system functions including attitude and trajectory determination, monitoring of spacecraft functions and environmental conditions, assessing ground system and spacecraft health status, ground system fault detection, orbital event and attitude-dependent prediction support utilizing advanced techniques such as fuzzy logic and neural networks. Assessing spacecraft health status and optimizing performance through in-flight identification, fault detection stabilization, and re-configurable control.
- Low power and mass propulsive attitude control actuators and related subsystem components. Actuators to consume less than one watt of power at three volts, providing impulse bits on the order of one micro-N-sec for 3-axis control or 40 milli-N-sec for spin-stabilized control.
- Innovations in GPS receiver hardware and algorithms that use GPS code and carrier signals to provide spacecraft navigation, attitude, and time:
  - Combined navigation and attitude space receivers. Advanced antenna designs.
  - Navigation techniques that may employ WAAS corrections.
  - Navigation, attitude, and control for spacecraft proximity operations.
  - Innovative uses of GPS which enable new Earth science measurements: for example, the use of differential GPS in repeating aircraft flight patterns; and the use of ocean-reflected GPS signals.
- Advanced GNC solutions for balloon-borne stratospheric science payloads, including sub-arcsecond pointing control, sub-arcsecond attitude knowledge determination and trajectory guidance.

8.4 SPACE SCIENCE

NASA's Space Science Enterprise seeks to discover the mysteries of the universe, explore the solar system, find planets around other stars, and search for life beyond Earth. From Origins to Destiny, the Enterprise seeks to chart the evolution of the Universe, its galaxies, stars, planets, and life. Its mission includes four science themes: Sun-Earth Connection - SEC (Space Physics); Solar System Exploration - SSE (Planetary Science); Structure and Evolution of the Universe – SEU (Astrophysics); and Astronomical Search for Origins and Planetary Systems. Each of these themes has a committee made up of both NASA and non-NASA scientists. Among their activities is the creation of a scientific roadmap for the next twenty years -- a plan for future space missions that will probe the mysteries of the universe.

http://spacescience.nasa.gov/

13 Large Optics Manufacturing Technology

Innovative products are sought that enable or enhance technologies critical to achievement of large-aperture, high-performance optical space telescopes at greatly reduced cost, weight, and packaging volume. This topic benefits the development of the Next Generation Space Telescope (NGST), a key element of NASA's Origins Program. The NGST is a six- to eight-meter aperture telescope that is to be launched in 2006 - 2007. The telescope will be designed to have near-diffraction limited performance in the range of wavelengths between 500 and 5000 nanometers and to operate at 30 K. The mass of the optical system is expected to be less than 1000 kilograms.

13.01 Space Based Large Telescopes
Lead Center: MSFC
Participating Center(s): GSFC, JPL, LaRC

The NGST, the Hubble Space Telescope Replacement, will be made much more powerful in resolution and light-gathering ability by greatly increasing the aperture size. It also will be necessary to operate the telescope at cryogenic temperatures and at a substantial distance from the Earth. Therefore, low mass of critical components such as the primary mirror and support and/or deployment structure is extremely important. It is also essential to develop actuators, deformable mirrors and other components for operation in a cryogenic environment. In order to meet the stringent optical alignment and tolerances necessary for a high quality telescope and to provide a robust design, there are potential significant benefits possible from employing systems that can adaptively correct for image degrading sources from inside and outside the spacecraft. This subtopic also includes correction systems for large aperture space telescopes that require control across the entire wavefront, typically at low bandwidth. The following technologies are sought:

- New lightweight mirror concepts development.
- New materials that reduce mass and improve performance.
- High precision fabrication methods and equipment to produce the highest quality optical surfaces.
- Metrology during fabrication to monitor, control, and verify results of the process.
- Technologies for testing new mirror materials and shapes in relevant environments.
- Segmented and membrane mirrors technology development.
- New coatings and methods for applying them.
- Lightweight structural concepts that enable packaging the large aperture into the relatively small launch vehicle payload envelope.
- Deployable optical benches to achieve reference baseline dimensions greater than those of the payload envelope.
- Innovative, precision, lightweight deployable mechanisms for segmented and thin membrane primary mirrors operating in a cryogenic environment.
- High resolution (2 nm) long stroke (6mm) cryogenic actuators.
- Powerful new analytical models, simulations, and evaluation techniques and new integration of suites of existing software tools allowing a broader and more in-depth evaluation of design alternatives and identification of optimum system parameters.
- Active and adaptive mirror systems that compensate for sources of distortion (structural deformations arising from misalignments, thermally driven dimensional changes and dynamics from overall vehicle motions, and moving mechanical systems onboard the spacecraft) to the image produced in the telescope.
- Innovative methods of detecting and characterizing errors.
- New control algorithms and methodologies for turning error information into corrective commands.
- Precision actuation to accomplish corrective measures.
- Embedded microelectronics to reduce the size and mass of an adaptive control system.
- Image stabilization technology enhancements.
- Measures that reduce the effects of the dynamics from internal mechanisms.
- Innovative solutions for momentum exchange systems.
- Momentum management systems that are not life-limited by consumables.

- Momentum management, pointing and attitude control, and on-orbit metrology systems that are integral with the adaptive and active correction system to achieve high optical performance, robust adaptability, reliability, and long life.
- Develop methods to conduct on-orbit system identification through the acquisition of experimental data for the purpose of correlating computer simulations and diagnosing possible structural dynamic problems. Structural excitation techniques that do not employ consumables should be developed as well.

The NASA Space Science Enterprise is studying future missions that will require very large space observatories. For example, the long range plan of the NASA Astronomical Search for Origins (ASO) theme is aimed at detection and characterization of planets in orbit around nearby stars. Independent of any specific instrument concept, the basic detection physics sets minimum requirements for the optical apertures of these future ASO missions. Set against the benchmark of the largest ground-based telescopes and the 8 meter NGST, terrestrial planet spectroscopic characterization requires a ten-fold increase in aperture area and low resolution direct imaging requires an additional 25-fold increase in area. Such large collection area requirements most likely preclude implementing the missions with single telescopes. Rather, such missions are currently envisioned to utilize constellations of large telescopes flying in formation and operating as interferometers. The basic building block for these systems is likely to be a diffraction limited optical collector of 20–40 meter diameter. Ultimately, to achieve higher resolution imagery and spectroscopy, even more aggressive architectures with much larger (100s–1000s of meters) aperture diameters and much lower areal densities will be required. In order to meet these challenging demands for future space interferometers, it will be necessary to develop new technologies in such areas as large lightweight optics, cryogenic optics and mechanisms, optical control, deployable optics, large optics testing, etc. The specific technologies NASA is seeking include:

- Large, ultra-lightweight optical and infrared mirrors including membrane optics for very large aperture space telescopes and interferometers.
- Ultra-precise, low mass deployable structures to reduce launch volume for large-aperture space telescopes and interferometers.
- Segmented optical systems with high-precision controls; active and/or adaptive mirrors; shape control of deformable telescope mirrors; image stabilization systems.
- Advanced, wavefront sensing and control systems including image based wavefront sensors.
- Cryogenic optics and mechanisms for space infrared telescopes and interferometers.
- Starlight nulling systems for optical and infrared interferometers.
- Nanometer and picometer metrology for space telescopes and interferometers.
- High-precision pointing and attitude control systems for large space telescopes and interferometers.
- Space-fabricated optics.
- High-performance materials and fabrication processes for ultra-lightweight optics.
- Advanced integrated modeling and simulation tools to analyze optical, thermal, and structural performance of large space telescopes and interferometers.
- Advanced, low cost large optics fabrication processes and test methods.

14 In-Situ Exploration and Sample Return

Solar system exploration is now embarked on a new phase, one that uses highly capable robotic space systems to explore the atmosphere, surface and subsurface of planets, satellites, and small bodies by means of in-situ measurements and sample return. Understanding the nature and history of our solar system, the similarities and differences between Earth and other planets, how life may have originated and persisted beyond Earth, and the potential for human habitation within the solar system are specific Space Science goals for which in-situ exploration is particularly relevant, if not critical. To accomplish the goals of future missions, innovative science payload technologies are needed for in-situ measurements of the atmosphere, surface, and subsurface. Novel devices and approaches are needed for deployment of instrumentation, positioning of in-situ instruments, acquisition of uncontaminated samples, containerization, and transfer of uncontaminated samples to sample collection sites or sample return vehicles. Innovations are also required to achieve the cleanliness requirements for planetary protection and integrity of samples used for in-situ analysis and sample return.

14.01 In-Situ Science Payload Systems
Lead Center: JPL
Participating Center(s): none

NASA's space science missions will increasingly rely on in-situ characterization of the atmosphere, surface and subsurface regions of planets, satellites, and small bodies. Achieving the solar system exploration goals will require innovative components and miniaturized instruments for in-situ analysis that offer significant improvements over the state-of-the-art in terms of size, mass, cost, power, performance, and robustness. These instruments may be deployed on surface landers and rovers, subsurface penetrators, hydrobots, and cryobots, and atmospheric sounders and probes. These instruments must be capable of withstanding extended operation in space and planetary environmental extremes, which include temperature, pressure, radiation, and impact stresses. A reasonable target for a science instrument concept is 1-kilogram mass, 1-liter volume, and 1 watt-hour of energy, although for mission critical capabilities, additional resources might be available.

Innovations in enabling instrument component and support technologies are also solicited. Topics include new sensors with improved performance relative to the state-of-the-art, as well as miniaturized valves, pumps, injectors, micro fluidics, and integrated sample-handling methodologies.

A wide range of in-situ instruments are of interest: geological, mineralogical, chemical, biological, physical, and environmental, with a near-term focus on Mars and Europa. This does not preclude the submission of proposals in areas of longer-term interest which include comets, asteroids, Venus, and the outer planets. Examples of technology challenges include, but are not limited to, the list provided below:

- Surface and subsurface chemical analysis of soils, rocks, and ices.
- Identification of signatures of extinct or extant life, or precursors of life.
- Mineralogy of rocks and soils.
- Geological stratigraphy.
- Geochronology.
- Chemical reactivity of Martian soil and rocks.
- Particle size distribution and morphology of surface soil and dust.
- Chemical analysis of planetary atmospheres.
- Isotopic analysis of solid and gaseous samples.
- Measurement of seismic, electromagnetic, and magnetic properties.
- Measurement of meteorological phenomenon.
- Characterization of the radiation environment (protons, neutrons, energetic cosmic).
- Particles (electrons and protons) and fields measurements for space plasma and solar studies.

14.02 Instrument Deployment, Sample Acquisition and Retrieval Systems
Lead Center: JPL
Participating Center(s): none

Future scientific exploration of planets and small bodies will require improvements in the tools for in-situ sample selection, collection, protection, and retrieval, and for placement of instruments on or below the surface. These tools will be required to operate in extreme environments including high temperature, high-pressure environments as well as low temperature, near vacuum environments. Novel devices and approaches are needed in the areas of manipulation and positioning of instruments; penetration of surface materials that have a wide range of properties; acquisition and storage of pre-determined amounts of material; protection of samples from handling and environmental damage; placement of samples into analysis systems; the transfer of samples to collection sites; and the on-surface or on-orbit rendezvous and docking with Earth-return systems. Example technology concepts include, but are not limited to, the following:

Surface Operations

- Mini-sample acquisition mechanisms with integrated feedback sensing.
- Low power miniature rock crushing and transport system.
- Impact technologies for rock fragmentation.
- Impulse cancellation/reduction techniques for sampling devices.
- Mini-extendable stinger/plunger end-effectors.
- Instrument placement techniques.

Sub-Surface Operations

- Low reaction force coring and drilling devices operating within planetary and small-body gravity environments.
- Low power rock ablation for spectrometry of subsurface materials.
- Anchoring techniques for microgravity bodies.

Atmospheric Operations

- Instrument deployment mechanisms from balloons and aerobots.
- Passive entrapment devices for atmosphere/particulate collection.

Operations in Wet Environments

- Sample acquisition in wet environments including mini-pump and transport systems.
- Sample acquisition within sub-surface ice environments.
- Passive entrapment devices for liquid collection.

Innovations Required for Sample Return Missions

- Sample confinement techniques for sterile insertion and maintenance of uncontaminated samples within a cache container.
- Sample containment techniques (biologic, thermal, and mechanical) for planetary sample return. Techniques should be robust to planetary, space, and Earth re-entry environments.
- Techniques for achieving, verifying, and maintaining biological cleanliness of instruments and sample acquisition hardware, in order to avoid contamination of the sample by terrestrial biomaterial, while minimizing compromises to instruments and hardware.
- Techniques for biological monitoring of samples throughout each phase of a sample return mission.
- Rendezvous and docking technologies for on-surface and on-orbit vehicle rendezvous.

15 Astrophysical and Space Physics Observations

The technical requirements to support the Structure and Evolution of the Universe (SEU) and the Sun-Earth Connection (SEC) science themes missions are extremely diverse, which is a consequence of the wide-ranging nature of the investigations. Technology developments are sought in the system context from energy detection through data reduction and scientific visualization needed to implement SEU missions. Technology developments are also needed in the areas of plasma, particle, fields and imaging sensors needed to support SEC missions.

15.01 Technologies for Studies of the Structure and Evolution of the Universe
Lead Center: GSFC
Participating Center(s): none

The SEU program seeks innovative technologies to enhance the scope, efficiency and resolution of instrument systems at all energies/wavelengths. Proposals are solicited for innovations ranging from readout electronics to optics systems that provide or enable order-of-magnitude performance enhancements. Achieving the increased measurement capabilities typical of future SEU missions requires instruments with substantially larger aperture sizes and focal lengths. Examples of supporting technologies from gamma rays to IR are included below:

- Large lightweight mirrors (rigid, deployable, or inflatable) for grazing incidence use at high energies (>10eV) and normal incidence use (<100eV) are required, with active surface shape control to correct for launch changes, thermal effects and pointing.
- Optical coatings are needed to optimize efficiency over broad wavelength ranges, and for narrow band discrimination, from hard x-rays using grazing incidence to normal incidence UV and multi-octave cryogenic-tolerant IR coatings.
- Dispersive elements such as variable line density gratings, blazed holographic gratings, focusing multi-order (curved echelle) gratings are needed to improve efficiency and resolution from hard x-rays to the IR.
- Improved filters are needed for x-ray discrimination, long wavelength rejection for energy-discriminating UV and x-ray detectors, and wide-field rugged tunable narrow-band filters for the UV and IR.
- Multi-object spectroscopy requires programmable masks or fiber arrays for selection of targets, for adjacent and dilute pixel arrays, including MEMS methods.
- Superconducting electronics for cryogenic detector readout are needed for use at all wavelengths from sub-mm to UV and x-rays: SQUID-based amplifiers and multiplexers for low impedance cryogenic sensors, and superconducting single electron transistors and multiplexers based on these devices for use with high impedance cryogenic sensors.
- Far infrared and submillimeter direct detectors suitable for background limited detection from cryogenic telescopes in space are needed.
- Cryogenic systems are required for cooling detectors below 0.1K for sub-mm photon counting arrays and energy dispersive arrays from x-rays to UV and IR.
- Advances are sought in lightweight, extendible optical benches, particularly in precision deployment mechanism design, passive thermal control, and disturbance isolation.
- For extendible reflectors, advances are sought in low-mass reflector panels, active alignment control, and nonlinear microdynamics modeling.

15.02 Sensing at Energies Greater than 5 eV (~2500 A)
Lead Center: GSFC
Participating Center(s): JPL

The next generation of astrophysics observatories for the ultraviolet (UV), x-ray, and gamma-ray bands require order-of-magnitude performance advances in detectors, detector arrays, readout electronics and other supporting and enabling technologies. Although the relative value of the improvements may differ among the three energy regions, many of the parameters where improvements are needed are present in all three bands. In particular, all bands need improvements in spatial and spectral resolutions, in the ability to cover large areas, and in the ability to support the readout of the thousands/millions of resultant spatial resolution elements. Increases in quantum efficiencies and decreases in background noise are required in the UV regions in order to improve the threshold for observing faint targets. The duration of the response of current x-ray calorimeters prohibits their use on the brightest objects.

- Superconducting tunnel junction devices and transition edge sensors for the UV and x-ray regions. For the UV, these offer a promising path to having "three dimensional" arrays (spatial plus energy). Improvements in energy resolution, pixel count, count rate capability, and long wavelength rejection are of particular interest. We seek techniques for fabrication of close packed arrays, with any requisite thermal isolation, and sensitive (SQUID or single electron transistor), fast, readout schemes and/or multiplexors.
- Advanced CCD detectors, including improvements in UV quantum efficiency and read noise, to increase the limiting sensitivity in long exposures and improved radiation tolerance. Electron-bombarded CCD detectors, including improvements in efficiency, resolution, and global and local count rate capability. In the x-ray, we seek to extend the response to lower energies in some CCDs, and to higher, perhaps up to 50 keV, in others.
- Improved microchannel plate detectors, including improvements to the plates themselves (smaller pores, greater lifetimes, alternative fabrication technologies, e.g., silicon), as well as improvements to the associated electronic readout systems (spatial resolution, signal-to-noise capability, dynamic range), and in sealed tube fabrication yield.

- Higher band gap materials for solid state detectors, leading to improved long wavelength rejection, lower dark current, and higher operating temperatures. Must ultimately be capable of producing large format arrays with low read noise.
- Large format detectors for use with "lobster eye" x-ray optics. Could be arrays of CCDs, silicon strip detectors, or gas micro-strip or micro-gap detectors, optimized for low energy x-ray operation in relatively low-rate environments.
- High-energy resolution Ge strip and pixel detectors. The spatial resolution of the pixels or strips should be as small as 0.5 millimeters.
- Improvements in the growth and characterization techniques for cadmium zinc telluride (CdZnTe) and the creation of pixelated arrays with pixel sizes in the range of 3 mm to 500 microns.
- High-sensitivity, high-energy-resolution, solid-state scintillation detectors.
- Improvements in readout electronics, including low power ASICs, and the associated high density interconnects and component arrays to interface them to the detector arrays.

15.03 Heliospheric Plasmas and Fields Sensors
Lead Center: GSFC
Participating Center(s): none

Research designed to improve our knowledge and understanding of the Sun-Planetary Connections requires accurate measurement or remote sensing of the composition, flow, and thermodynamic state of space plasmas and their interactions with atmospheres. Low energy charged particle analyzers and DC to RF electromagnetic field sensors provide direct in-situ measurement. Complementing direct measurements, fast neutral atom imagers, Radar, IR, UV and X/Gamma-ray photon imagers all provide wide-ranging remote sensing of energetic phenomena occurring within space plasmas or upper atmospheres. This instrumentation is often severely constrained by spacecraft resources. Therefore, miniaturization and autonomy are common technological development themes across this entire category of sensors. Specific technologies are sought in the following categories:

Plasma Sensors
- Improved techniques for imaging of charged particle velocity distributions.
- Techniques for the high-efficiency imaging of energetic neutral atoms, with conversion of low energy neutral atoms to ions.
- Improved techniques for the regulation of spacecraft floating potential near the local plasma potential, with minimal impacts on the ambient plasma and field environment.
- Low power digital time-of-flight analyzer chips and waveform generators with sub-nanosecond resolution and multiple channels of parallel processing.
- Miniaturized, radiation-tolerant, autonomous electronic systems for the above.

Field Sensors
- Improved techniques for measurement of plasma floating potential and DC electric field (and by extension the plasma drift velocity), especially in the direction parallel to the spin axis of a spinning spacecraft.
- Measurement of the gradient of the electric field in space around a single spacecraft or cluster of spacecraft.
- Improved techniques for the measurement of the gradients (curl) of the magnetic field in space local to a single spacecraft or group of spacecraft.
- Direct measurement of the local electrical current density at levels typical of space plasma structures such as shocks, magnetopauses, and auroral arcs.
- Miniaturized, radiation-tolerant and autonomous electronic systems for the above.

Electromagnetic Radiation Sensors
- Improved techniques for spectrometric imaging of IR emissions from planetary atmospheres and ionospheres, such as large array (8 Mpixel) CCD cameras (0.35-2 micron), holographically enhanced Fabrey-Perot interferometers, and tunable IR lasers (2-5 micron) based on, e.g., quantum cascades.
- Improved techniques for spectrometric imaging of visible and UV emissions from regions of energetic plasma phenomena interacting with atmospheric gases, such as aurora and day-glow cameras.

- Improved techniques for spectrometric imaging of X/Gamma-ray emissions from planetary and cometary atmospheres and ionospheres, such as solid state photomultiplier devices for use in combination with scintillation detectors.
- Radar sounding and echo imaging of plasma density and field structures from orbiting spacecraft.

16 Interferometer Technology

Stellar interferometry figures prominently in NASA's plans for 21st century Space Science. As part of the Origins Program three major visible and near-infrared interferometry missions are now underway (the Deep Space 3 formation flying technology mission, the ground-based Keck Interferometer, and the Space Interferometry Mission) and others spanning from x-ray to sub-millimeter to gravity wave are planned for the coming decades. Both monolithic and free formation flying interferometer systems are contemplated, as well as nulled imaging to discriminate faint objects in the near vicinity of very bright ones. The objective in all cases is to use the extraordinary resolution offered by interferometry to explore the structure of our universe as seen across the electromagnetic spectrum and as represented by gravitational waves generated by the dynamics of dense matter regions. This topic is looking for high-payoff, innovative concepts that will help to achieve the interferometry goals, including reduction of cost and schedule. The common technical challenges of interferometry include extreme tolerances: path-length measurement precision of up to 1 exp-5 wave over distances ranging from meters to 1 exp9 meters; positional stabilization of up to 1 exp-4 wave for periods of up to 1 exp4 seconds; and system level modeling, integrations and test. Relevant technologies include: laser metrology, active optics, thermally stable optics, nulled imaging optics, precision deployable structures, vibration isolation and suppression, formation flying, drag-free payloads, and integrated modeling software.

16.01 Interferometry Technology
Lead Center: JPL
Participating Center(s): none

The next generation of astrophysics interferometry missions will require highly precise control of active optical systems mounted on flexible structures and/or distributed among spacecraft flying in precision formation. Innovations are needed in instrument design and fabrication, optical components, detectors, structures and special purpose spacecraft subsystems. Instrument performance extension into the 1-angstrom x-ray, the 5 to 27 micron infra-red and the 40 to 400 micron sub-millimeter regimes is desired.

Laser Metrology

- Laser metrology gauge systems and components are needed to provide the high-finesse baseline range sensing. Precision requirements vary with application, ranging from 50 picometers for a 10 meter baseline to 10’s of nm for a 1 km baseline, and a few picometers for a thousand kilometer baseline. Full aperture metrology gauge schemes appear to be essential.
- Metrology laser, greater than 1 watt single mode power with very narrow linewidth (typically a few kiloherz) and stable frequency (1 Hz rms at 100 second time scales).

Single Mode Waveguide Components

- Single mode optical waveguide systems and components with low polarization cross-talk are needed for the 7 to 27 micron infra-red regime.

Beam Combiners

- Cryogenic nulled beam combiners are required for discriminating faint objects in close proximity to very bright ones (for example, exo-planets in orbit around their sun). A nulling ratio of 10 exp-6 is required over the 7 to 27 micron wavelength regime.

Active Optics
Methodologies, hardware components, and systems are required to provide pathlength, tip/tilt and wavefront control including:

- Wavefront sensors, l/1000 wavelength accuracy for use in the visible and in the 7 to 27 micron regions.
- Adaptive optics systems and components, including deformable mirrors with > 10,000 actuators.
- Thermally stable, high accuracy gimbals (+,- 7.5 deg f.o.r., 17 mas stability for 1 sec).
- Thermally stable, > 100 Hz, momentum-compensated steering mirrors.
- Six DOF pointing and displacement mechanisms, with nanoradian and submicron-level precision and stability.
- Optical delay lines for the visible and infrared with meter-long travel and picometer precision.
- Thermally stable nano-mechanical actuators.

Thermally Stable Optics
- Optics which maintain figure to 1/1000 to 1/10000 of a wave when cooled from room temperature to 40K.

Precision Deployable Structures
- A new class of deployable structural concepts and approaches capable of achieving post-launch deployment deformations to within 1 micron; maintaining structural linearity and repeatability in the deployed condition; and retaining the desired features of reliability, reduced weight and stowed launch volume will be required. The linear baseline of the deployed structures ranges from 10-20 meters.

Vibration Isolation and Suppression
- Concepts, components, subsystems, algorithms, and software to isolate, attenuate and suppress vibrational motions of the structure and key components when subjected to excitation over a broad frequency range. The amplitude of the vibrations to be suppressed is in the 1-10 nanometer range, with frequencies ranging up to 100 Hz.

Formation Flying
- Systems, sensors, thrusters and control algorithms to establish and maintain free-flying interferometer spacecraft constellations. Positional accuracy and stability of several microns with a spacecraft-to-spacecraft baseline of 10 km are required.

Drag-Free Payloads
- Concepts, systems, components and control algorithms for a drag-free payload to follow an isolated inertial proof mass to within nanometers in free space. Non-gravitational acceleration noise of the proof mass to be less than 3 exp –15 m/s/s/sqrt(Hz).

Integrated Modeling Software
- Innovative approaches for structural modeling capable of characterizing broadband dynamic response.
- New concepts to reconcile integrated structural models to measured data.
- New techniques to accurately predict synthesized model response from component level tests.
- Structural modeling techniques for thermally induced vibrations in joint-dominated structures.
- Integrated design optimization techniques and algorithms for precision optical systems.
- Analytical characterization of nanometer-level static, thermal and dynamic induced structural distortions for optical elements, opto-mechanical components and precision deployment mechanisms.
- Novel test concepts and approaches to verify accuracy of high-fidelity integrated model predictions.

8.5 THRUST AREAS

In addition to the above research subtopics specific to each Enterprise, this section captures critical technologies that may support multiple Strategic Enterprises. Thrust Area topics reflect the current agency management structure for these cross-enterprise technologies.

17 Advanced Power and Onboard Propulsion

The Advanced Power and Onboard Propulsion Thrust will provide technologies that will significantly reduce spacecraft and mission costs, increase mission capabilities and enable revolutionary concepts such as virtual spacecraft constellations. Areas of special interest are very high efficiency photovoltaics, advanced energy storage (such as Lithium polymer batteries and capacitors), advanced electric and chemical propulsion thermal management, and space power materials and structures.

17.01 Energy Conversion and Storage and Electric Power
Lead Center: GRC
Participating Center(s): JPL, JSC

Innovative concepts for systems and components are solicited in the areas of both static and dynamic energy conversion systems. Power levels of interest range from tens of milliwatts to many kilowatts. This area includes photovoltaics, AMTEC, thermophotovoltaics, thermoelectrics, thermionics and thermodynamic conversion systems. Additionally, NASA programs require energy storage systems having high energy-density and cycle life. This includes rechargeable batteries, fuel cells and competing alternatives with high-power-density such as lightweight flywheels and ultra-capacitors. Specific areas of interest are:

- Photovoltaic technology with targeted cell efficiencies over 30 % and array performance up to 1000 watts per kilogram and 400 watts per square meter. Potential concepts include rigid arrays, thin film arrays, and various concentrator configurations. High radiation resistance also is a requirement for some missions, as is operation in low temperature, low intensity or high temperature, high intensity conditions
- Advanced solar thermal power conversion technologies for Earth orbiting spacecraft and/or orbit transfer vehicles. Concentrators may be rigid or inflatable, primary or secondary and address issues such as manufacturing, coatings, efficiency, packaging/deployment, and pointing/tracking. Receivers may utilize heat pipe or direct absorption technologies intended to minimize mass and volume. Topics of interest in power conversion include the investigation of compact heat exchangers, advanced materials, and control methods, as they relate to life, reliability and manufacturability. Heat rejection areas of interest include composite materials, heat pipes, pumped loop systems, and packaging and deployment. Also of interest are highly integrated systems that combine elements of the above subsystems and show system level benefits.
- Thermal-to-electric conversion concepts are sought that would utilize Radioisotope Heater Units (RHUs) or General Purpose Heat Source (GPHS) modules as heat sources and have electrical outputs from tens of milliwatts to 100's of watts and efficiencies greater than 20 %. Systems of interest include AMTEC, thermophotovoltaics, thermoelectrics and Stirling. Small lightweight heat reaction systems are also needed. Concurrent with NASA's trend toward micro-satellites, NASA also has an interest in power systems based on micromachining fabrication techniques.
- Nickel-hydrogen and nickel metal hydride battery technology with goals of at least 100 watt-hour per kilogram and 10-year life in LEO and GEO for spacecraft and space systems. Also, lithium and lithium-polymer batteries for planetary spacecraft and probes with goal of 200 watt-hour per kilogram for low and/or wide temperature operations.
- Proton exchange membrane and solid oxide fuel cell and fuel cell-electrolyzer systems.
- Portable, rechargeable energy storage concepts with increased energy density over Ni-Cd and Ni-H2, but which require only hundreds, not thousands of cycles. Proposed concepts for EVA and in-cabin energy storage can include a variety of approaches such as secondary batteries, fuel cells, ultra or super capacitors or flywheels; however, the primary criteria are high energy density (both weight and volume) portability, and safety. For unique applications requiring few "cycles" very high energy density primary battery systems are of interest where sufficient energy storage can trade against rechargeability.
- Demonstration as a pilot project of a flywheel energy storage unit for use as an uninterruptable power source (UPS). The flywheel system will be run in parallel with an existing UPS for 60 Hz backup power.
- Future planetary missions require high specific energy and high energy density primary and rechargeable batteries capable of operating at low temperatures. Planetary probes require primary batteries capable of providing >500 Wh/kg specific energy and >1000 Wh/l at ambient temperature. Further, these batteries must

be capable of delivering 30-50% of their ambient specific energy at temperatures as low as -100 C. Lithium primary with advanced cathode materials and electrolytes and other advanced electrochemical systems having these capabilities are of interest. In the rechargeable lithium battery area, the primary technology drivers are specific energy (>150 Wh/kg), energy density (>300 Wh/l), cycle life (>1000 deep discharge cycles) and low temperature operating capability (-60 C to ambient). Rechargeable lithium ion batteries with advanced anode and cathode materials and liquid/polymer electrolytes and other advanced battery systems capable of meeting the above performance criteria are of interest.

Future planetary missions (landers, rovers, probes, orbiters) require high specific energy and high energy density primary and rechargeable batteries capable of operating at low temperatures. Future planetary micro-spacecraft require distributed micro power sources that can operate over a wide temperature range. Planetary probes require primary batteries capable of providing >600 Wh/kg specific energy and >1200 Wh/l at ambient temperature. Further, these batteries must be capable of delivering 30-50% of their ambient specific energy at temperatures as low as -100 C. Lithium primary batteries with advanced cathode materials and electrolytes and other advanced electrochemical systems having these capabilities are of interest. Landers and rovers require rechargeable lithium batteries with high specific energy (>200 Wh/kg), and energy density (>400 Wh/l), moderate cycle life performance capability (>1000 deep discharge cycles) and good low temperature performance (-60 C to ambient). Further these missions require batteries with low self-discharge and minimal performance loss over extended period (months-years). Planetary orbiters require rechargeable lithium batteries capable of providing > 30,000 cycles at 20-30% depth of discharge. Rechargeable lithium ion cells with advanced anode and cathode materials and liquid/polymer/solid electrolytes are of interest. Other advanced battery systems capable of meeting the above performance criteria are of interest. Future Micro spacecraft require distributed power sources that are integrated with microelectronics devices/instruments. These microelectronic devices/instruments require rechargeable batteries/fuel cells that can provide power in the range of micro to milliwatt range and can operate over a wide temperature range (-100 to 100 C). Long cycle life performance capability is also needed for micro rechargeable batteries. Successful implementation of these technologies requires in-depth understanding of the basic cell chemistries and processes that can be obtained through first principles cell modeling. Proposals on the cell/battery modeling effort are also of interest.

17.02 Power Management and Distribution
Lead Center: GRC
Participating Center(s): JPL

Innovative concepts utilizing advanced technology are needed to manage and distribute power in lighter, smaller, cheaper, more durable, and high performance spacecraft and to improve reliability and reduce overall costs (including operations) for advanced transportation systems. Advances for power management and distribution (PMAD) systems are sought in the following areas:

- Materials, surfaces, and components that are durable for atomic oxygen, soft x-ray, electron, proton, and ultraviolet radiation and thermal cycling environments, lightweight electromagnetic interference shielding, and high-performance, environmentally durable radiators.
- Advanced electronic materials, devices and circuits, including, but not limited to, transformers, transistors, integrated circuits, capacitors, ultra capacitors, electro-optical devices, micro electro-mechanical systems (MEMS), sensors, low loss magnetic cores, and packaging with improved characteristics capable of high-temperature, low-temperature (cryogenic), or wide-temperature operation or radiation resistance for use in PMAD systems, motor drives, electrical actuation, or electro-mechanical systems.
- Management, control and monitoring of power systems, adjustable speed drives, or autonomous operation of space power systems.
- Thermal control technologies that are integral to electrical devices with heat flux capability of at least 100 W/cm2 (show estimated heat transfer versus pressure drop).
- Advanced electronic packaging technologies that reduce volume and mass or combine electromagnetic shielding with thermal control.

- Fault detection, isolation, and system reconfiguration, including "smart components", built-in test, and vehicle health management concepts.
- Advanced PMAD electronics for small low cost spacecraft to simplify interfaces, streamline integration and testing, and reduce size and mass.
- Advanced power-conditioning devices for housekeeping and control of a wide range of regulated voltages on Space and Earth Science payloads to reduce size and mass utilizing hybrid, multi-chip, and other techniques.
- Modular, integrated spacecraft PMAD building blocks which drastically reduce system size, mass, and recurring cost through the use of the highest levels of integration based on monolithic, application-specific integrated circuits, mixed mode application-specific integrated circuits, field programmable gate arrays, advanced power packaging techniques, and flexible reusable architectures.
- Improved wiring system designs, new fault detection techniques, and advanced circuit protection to improve safety, reliability, and performance of aerospace systems and vehicles.

17.03 Materials and Structures for Propulsion and Power
Lead Center: GRC
Participating Center(s): none

Materials for Propulsion and Power
Technologies to be addressed relate to advanced materials, their development, and their application to primary propulsion systems (e.g., aircraft gas turbines, rocket-based combined cycles,) and space transportation propulsion systems and to aerospace power systems, (e.g., flywheel energy storage, power conversion, and distribution), as well as to auxiliary power sources in aircraft and space vehicles. Proposals are sought to address the following areas:

- High temperature polymers and polymer matrix composites for long life space and aero-applications at temperatures from 140 deg. C to 320 deg. C.
  - Materials and related technologies (automated cure, resin transfer molding, weaving and braiding) to enable low cost manufacturing of composite components.
  - Methods and materials for large structure non-autoclave curing.
  - Cost competitive non-mutagenic diamines for use in high temperature polyimides, in particular low cost routes for synthesis of alpha-alpha prime-bis (4-aminophenyl)-p-xylene (BAX).
  - Electron beam curable polyimides for high temperature applications.
  - Processable adhesives of low void content.
  - Overlay coatings for oxidation and erosion protection.
- Metallic materials
  - Intermetallics, including $MoSi_2$, NiAl, and especially TiAl.
  - Nickel-base superalloys.
  - High thermal conductivity copper alloys and composites, and associated coatings.
  - Low cost processing and joining technology for the above.
  - Development of advanced computational materials modeling tools.
- Magnetic Materials
  - Soft magnetic materials exhibiting high strength and low eddy current and hysteresis losses for use in flywheel and gas turbine engine magnetic bearing systems.
- Ceramic matrix composites
  - Stronger, more creep-resistant high-temperature fibers.
  - Environmentally resistant and/or low cost fiber coatings for SiC and C reinforced and oxide/oxide composites.
  - More affordable and stronger, tougher, and more environmentally durable carbon or silicon carbide fiber reinforced composites.
  - Low cost alternatives to fiber reinforcement.
- Lubricants, Tribology
  - Liquid, vapor phase, and mist lubricant formulations for gas turbine engine applications to 400 C.
  - Wear resistant and fretting fatigue resistant coatings for titanium alloys.

  - Solid lubricants for high-speed (e.g., 50k to 500k rpm) touchdown bearings for magnetically suspended flywheels in satellite applications. Must be vacuum compatible, have low friction and high load carrying capability, be compatible in thin film form with liquid lubricants, and be impact resistant.
- Thermal Barrier Coatings (TBC) with emphasis on nondestructive evaluation and life prediction
  - Quality control of plasma sprayed and physical vapor deposited TBCs.
  - Operational inspection of TBC coated parts enabling identification/overhaul/replacement prior to engine damage.
  - Realistic TBC failure/life prediction models.
- Research and Development of Unique Materials Fulfilling Special Propulsion and Power Requirements
  - Electrically conductive but clear polymers.
  - Electrical insulators with high thermal conductivity.
  - Low sputter yield, low coefficient of expansion, high modulus, high temperature metals.
  - High temperature flexible electrical insulators.
  - High temperature, aggressive combustion environment resistant, chamber material systems.
  - Carbon-carbon grids for advanced ion engines.
  - Silicon carbide or other high temperature microchip materials for micro-electro-mechanical systems (MEMS) propulsion applications.

Structures for Propulsion and Power

Proposals are sought for innovative and commercially viable concepts for structural and mechanical components and subsystems of Aerospace Propulsion and Power Systems. Innovative concepts for structural and mechanical components and subsystems of advanced "Space Propulsion Systems" are also sought. The focus is on problems related to structural and mechanical components and subsystems that operate at extreme temperatures, in hostile aero-thermo-chemical ground environments or in space environments, at high stresses, under cyclic loading conditions. The objective is to provide structural and mechanical concepts that enable more reliable operation, increased efficiencies, reduced design-to-production time, and reduced life-cycle costs.

- <u>Machinery Dynamics</u>. Innovative mechanical systems for controlling destructive aeroelastic and rotordynamic instabilities and vibration in turbomachinery for Aeronautical and Space vehicle applications. Specific items of interest are:
  - Propulsion Aeroelasticity.
  - Blade vibration dampers reduction methods, i.e., platform dampers, integral blade dampers, mistuning.
  - Blade Deflection and Tip Clearance Measurement Systems.
  - High Temperature (e.g., 1000^{o}F) and Low Temperature (e.g., –422^{o}F) Coils, Probes, and Magnetic Bearings.
  - High Speed (e.g., 50,000 to 100,000 rpm) Touch-down or Back-up Bearings for Magnetically Suspended Flywheels for Space Station and Satellite applications.
  - Circumferential/axial graphite composite bearings-balls, cages, and races. Health monitoring techniques for in-situ monitoring of rotating machinery are sought for the purpose of detecting incipient failures. The ability to reliably detect incipient failures before they occur and shut down or operate at reduced capacity is highly desired in both flywheel and turbomachinery applications.
- <u>Structural Mechanics Computational Methods</u>. Analytical tools for simulating the performance of critical structural components and systems; optimizing and tailoring their capabilities; and modeling life-cycle performance from material selection to system requirements. Areas of interest for both Aeronautical and Space applications are:
  - Life-Cycle Modeling.
  - Composite structures.
  - Smart Structures.
  - Multi-disciplinary design optimization and tailoring - deterministic and probabilistic.
- <u>Advanced Seals Development</u>. Proposals for the development and evaluation of advanced seal concepts under simulated conditions are sought in the following general areas:

- Turbomachinery seal concepts showing promise of long-life operating under extreme surface speed (1500 fps) and temperature conditions. Special consideration will be given to non-contacting sealing approaches.
- Structural seal concepts showing promise of significant resiliency and distortion following capability under extreme temperature conditions (2000+deg F) for "Re-entry Vehicle Thermal Protection Systems" and launch vehicle engine nozzle ramp locations.

- Multifunctional Materials and Structures. Multi-functional materials and structures that serve as power and/or information conduits as well as structural members may be valuable to increase performance and efficiency or reduce weight, size and complexity of Aeronautical and Space systems. Research oriented to support the following issues is sought:
  - Mechanical characterization of multi-functional materials such as electrical conductors which also serve as sensory/active "smart" structural members.
  - Development of thermal and structural multi-functional materials and structures.
- Life-Prediction. Life-prediction models and failure theories for assessing the durability and integrity of structural components manufactured from advanced high-temperature materials for aerospace applications. These materials include advanced metallics; intermetallics, ceramics and polymeric and ceramic matrix composites. Technical areas of interest include:
  - Damage mechanics and viscoplastic constitutive models.
  - Fatigue crack initiation and growth models.
  - Brittle structures modeling.
  - Fracture mechanics/modeling.
- Experimental Mechanics. Experimental research at the coupon level investigating the physical mechanisms of deformation and damage in advanced aero and space propulsion materials. Experimental research at the subelement level aimed at the verification/validation of analytical models and analysis methods under prototypical loading conditions. Areas of interest are:
  - Non-destructive evaluation methods and standards.
  - Mechanical test methods and standards.
  - Benchmark structural testing.
- Probabilistic Durability, Reliability, and Risk Assessment. Proposals are solicited for the development of computational probabilistic methods for both serial and parallel-processing platforms in the following areas:
  - Microscopic and macroscopic damage initiation.
  - Participating failure mechanisms.
  - Specimen/component fracture modes.
  - Failure mechanisms include, but not limited to: fatigue, excessive inelastic deformation, creep rupture, creep-fatigue interaction, thermomechanical fatigue, and others such as wear, galling, fretting, etc.

17.04 Thermal Control and Cryogenic Support Systems
Lead Center: GSFC
Participating Center(s): ARC, JPL, JSC

Future spacecraft, space facilities, and instruments will require increasingly sophisticated thermal control technology and may operate in increasingly severe thermal environments. Heat load centers may be more numerous and more widely dispersed, flux levels may increase, and very tight temperature control will be required. Some applications may require significantly increased power levels while others may require extremely low heat loss for extended periods. Some applications call for low to moderate operating temperatures while others require extremely high temperatures (over 2300K). The advent of very small spacecraft will also drive the need for new technologies, particularly since such small spacecraft will have low thermal capacitance. Both the lifetime and the reliability of the cryogenic systems are critical performance concerns. Mechanical coolers, thermoelectric coolers, radiative coolers, stored cryogenic fluids and combinations of these will be considered. Of particular interest are cryogenic coolers for cooling detectors, telescopes and instruments; for the storage and liquefaction of cryogenic propellants; and for hybrid systems in the 0.05 to 150 K temperature range. In general, long life, low cost, low weight, and high reliability are prime technology drivers. Specific areas of interest include, but are not limited to, the following;

- Cryogenic (4 K to 40 K) heat pipes, loop heat pipes, and CPLs with diode and flex capabilities and highly reliable Loop Heat Pipes and CPLs which allow multiple heat load sources and multiple sinks.
- Advanced wicks (2 micron or less) for capillary devices.
- Advanced devices and/or techniques for thermal control of chip level electronics, focusing on thermal control of COTS electronics.
- Advanced thermal control coatings such as variable emissive surfaces that are controllable and a white, sprayable, conductive, thermal control coating with low outgassing characteristics.
- Low mass, high performance, modular heat pumps for unmanned (spacecraft and balloon) applications.
- Advanced thermoelectric coolers capable of providing 100s of milliwatts of cooling at 150 K and below.
- Phase change and intelligent, adaptive control for thermal control devices.
- Advanced analytical techniques for thermal modeling, focusing on techniques that can be easily integrated with emerging mechanical and optical analytical tools.
- Innovative means of integrating thermal control devices with other spacecraft/instrument subsystems.
- Instrumentation and automated software that will enhance system thermal control and monitoring, and allow location/isolation of component failures, and for performing recovery operations.
- Highly reliable, efficient, low cost Stirling, pulse tube, reverse Brayton, magnetic, solid-state cooler technology and hybrid systems, including those with radiative coolers. Emphasis will be placed on technologies leading to small, low-mass, low cost cooling systems.
- Future missions to the Martian or Lunar surface will take advantage of indigenous resources for producing propellants. Liquid oxygen, and potentially other cryogens, will be produced and stored on the planet surface. Innovative technologies are needed for the cryogenic support systems for these propellant production and storage units. Specific technology areas include high capacity liquefaction systems for oxygen; cryocooler systems with high cooling capacity (>25 watts); very low heat leak oxygen dewars; and efficient hydrogen storage systems for transporting hydrogen to Mars and storing hydrogen on Mars.
- Low cost compressors and pulse tube cooler efficiency improvements for 0.1 - 10 W cooling in the 7 - 120 K range for space missions; coolers for robotic and manned missions to the Moon and Mars, with requirements from 100 W @ 20 K with 1 year life to 10 W @ 90 K with 7 year life; a 0.5 W @ 100 K cooler that can start after 4 years of storage at temperatures down to 100 K; phase change thermal reservoirs or passive storage technology in the 100 - 250 K range for returning samples from planets, asteroids, and comets; and novel micro-scale coolers for integrated focal plane packages.
- Innovative technologies for: hybrid coolers using sorption refrigeration lower stage integrated with a radiative upper stage to provide 100 mW at 10 to 40 K; temperature stability enhancement for solid hydrogen sublimation stages in continuous 10-K sorption cryocoolers; low cost, light weight cryogenic (60 K to 120 K) radiators; active and passive vibration cancellation of mechanical cooler generated vibration, both at cryogenic and ambient temperatures. Other areas of interest include: stable, high conductivity interface materials, high conductivity, low coefficient of thermal expansion (CTE) materials; and high conductivity, flexible thermal links.
- Microgravity science and processing applications call for: advanced light weight insulation, durable, high watt density heaters, thermally conductive and/or insulating flexible interface materials that can operate at extremely high temperatures; highly accurate, remotely monitored, in-situ, non-intrusive thermal instrumentation for meeting science and manufacturing and safety needs; high temperature vacuum compatible fittings and connectors; and materials and concepts for thermally efficient containment and processing of hazardous materials and samples; low vibration or vibration isolating fluid components including fans, pumps, compressors, coolers, tubing, fittings, heat exchangers, and valves.

Future human space missions will operate in more severe environments than in the past. There is a need for highly efficient, lightweight, low power and reliable internal and external active thermal control systems for piloted spacecraft, rovers and planetary bases. Areas in which innovations are solicited include the following:

- Fault tolerant fluid to fluid heat exchangers that cannot fail in a way which permits leakage between fluid loops.
- Heat pumps to acquire waste heat at near 0 degrees C and reject the heat via a radiator at approximately 50 degrees C.

- Internal heat pumps to provide cabin dehumidification with a fluid heat sink of 15 to 25 degrees C.
- Flexible radiators which can be stowed compactly for transport and deployed for use.
- Micro-meteoroid tolerant and freeze/thaw tolerant radiators.
- Environmentally friendly, non-toxic single and two-phase working fluids that either freeze below 75 degrees Kelvin or do not significantly change density upon freezing or thawing.
- Low power two-phase heat transport loops and associated controls.
- Thermal energy storage systems.
- Controllable water evaporator heat rejection devices for use in vacuum environments.

Proposers should indicate how their research is expected to improve the mass, power, volume, safety and reliability of future active thermal control systems as compared to state-of-the-art technologies.

17.05 In-Space Propulsion
Lead Center: GRC
Participating Center(s): JPL

Innovations are sought to enhance propulsion capabilities for a wide range of spacecraft (e.g., communications and remote sensing satellites, interplanetary spacecraft, microsatellites) for functions including orbit insertion, orbit maintenance, precision positioning, de-orbit, reaction control, and planetary primary propulsion. Both chemical and electric onboard propulsion technologies are of interest at the component, sub-system, and system level. Key aims of this subtopic are technology advancements which will lead to 1) significant miniaturization; 2) reduced costs in the system components and/or ground servicing; 3) prolonged mission or systems lifetimes; 4) improved reliability; and/or 5) enabling mission functions.

Areas of interest include:

- Propulsion technologies for satellites and spacecraft in the 10- to 100-kg (micro) and less than 10-kg (nano) class. These propulsion concepts should emphasize system simplicity, low power requirements, and minimal mass. Micro-electro-mechanical systems (MEMS) propulsion concepts are of particular interest.
- Propulsion technologies to provide high-precision (impulse bit < 100 mNs) stationkeeping and attitude control for small satellites and spacecraft.
- High-power (100 kW to 1 MW) electric propulsion technologies for HEDS and space solar power applications.
- Electric propulsion technologies for unmanned Earth-space and planetary transportation applications, including thrusters, advanced power processing, and propellant management components.
- High-performance (specific impulse > 235 s), monopropellant technologies, including propellant formulations, catalytic and non-catalytic ignition concepts, and propellant management components.
- Radiation-cooled rocket chamber materials for long-life (> 6 hours) operation in high-temperature, aggressively oxidizing combustion environments. In particular, innovative fabrication technologies are sought for refractory carbide matrix composites and metal-lined composites.
- Propellant management components for electric and chemical propulsion systems. Components should reduce total propulsion system mass and volume by a factor of two or better, while maintaining or improving reliability and performance of existing chemical components and systems. Components include propellant storage and expulsion devices, propellant feed systems, valves, absolute isolation devices, flow management and regulation devices, and thermal control hardware for chemical systems. For electric systems, technologies of interest include energy storage and delivery, propellants and feed, initiation and long life, and control. Components for miniature systems include very low-leak rate valves, regulators, flow control devices, multifunctional components, and ignition sources.

18 Breakthrough Sensors and Instrument Component Technology

The Breakthrough Sensors thrust area topic is seeking innovative instrument technologies that will enable order of magnitude improvements in NASA's capabilities in both remote and in-situ sensing. The goals of the thrust are the development of fundamentally new measurement principles; the enabling of new observation capabilities for astrophysics, space physics, planetary exploration, astrobiology, and Earth science; the incorporation of new physical, chemical and biological sensors into long duration human space systems. The technology elements in the thrust include focal planes, instrument optics, cooling systems, radar, lidar, and submillimeter receivers, lasers, photonics, particle and field detectors, and in-situ sensors (e.g., seismometers, mass spectrometers, chemical sensors). Incorporation of novel micro- and nano-scale technologies, enabling new measurement strategies, is a strong interest for this topic. The ability to operate in the extreme environments of NASA missions (temperature, radiation, corrosive atmospheres, high pressure, long lifetime, shock) is a key for advances in this area. Another primary driver for products in this area is the need to greatly reduce instrument demands on mission resources (mass, power, cost, volume, cooling, calibration, stability, etc.).

18.01 Instruments for Exobiology
Lead Center: ARC
Participating Center(s): none

Exobiology seeks to understand the origin and evolution of life and life-related processes and materials throughout the universe. This requires a specialized cadre of advanced analytical instruments and systems for future solar system exploration missions. In light of a pending sample return, Mars is of special interest for both Earth-based laboratory applications as well as flight experiments. New analytical devices must be highly accurate and precise while performing meaningful analyses on very small samples containing exobiologically-important elements (C,H,N,O,P, and S) and their compounds, e.g., H_2O, NOx, CH_4. Typically, advanced instruments would identify and measure biogenically-important chemical and elemental components of extraterrestrial atmospheres, soils, ices, sedimentary rocks, and minerals, e.g., evaporites, clays, and silica, cometary materials. Miniaturization and other techniques to decrease hardware complexity and increase flight capability of the devices or systems for efficient use of spacecraft resources is paramount. Examples include, but are not limited to, the following:

- Gas chromatographs, including innovative detectors, columns, and samplers, for identification and detection of gases and organic compounds at parts-per-billion levels.
- Infrared reflectance and transmittance spectrometers and subsystems to conduct molecular spectrometry of extraterrestrial surface samples and to identify and measure the C, O, and N isotopes contained in CO_2 and NOx with precision of 0.1 % or better.
- Electrochemical or other elemental and geochemical devices or sensors to sensitively measure composition of single or multiple extraterrestrial surface and atmospheric components, e.g., H_2O, CO_3.
- Novel or advanced chemical analyzers, e.g., ion mobility spectrometers, Raman spectrometers, for molecular analysis of nanogram or smaller quantities of exobiologically-important molecules.
- Remotely operated device that illuminates and provides full color images of rocks and soils with magnification range of 2-100x.
- System for obtaining and delivering representative extraterrestrial materials, e.g., Mars soils, from a minimum depth 1 meter for return to Earth.
- Containment systems for returning the extraterrestrial materials samples (atmosphere, evolved gases, rocks, particulates or dust, and core sections are all desired) to Earth after collection. Such systems must isolate and maintain pristine (uncontaminated) samples with retained volatiles during handling and transit to Earth. Forward and backward biological isolation of the sample is critical.

08.02 Technologies in Support of Astrobiology Studies
Lead Center: ARC
Participating Center(s): none

Astrobiology includes the study of the origin, evolution and distribution of life in the universe. New technologies are required to enable us to search for extant or extinct life elsewhere in the solar system, to obtain an organic history of planetary bodies, to discover and explore water sources elsewhere in the solar system and to distinguish microorganisms and biologically important molecular structures within complex chemical mixtures. The search for life on other planetary bodies will also require systems capable of moving and deploying instruments across and through varied terrain to access biologically important environments.

A second element of Astrobiology is the understanding of the evolutionary development of biological processes leading from single cell organisms to multi-cell specimens and to complex ecological systems over multiple generations. Understanding the effects of gravity on the evolution of living systems is a fundamental question of substantial, inherent scientific value in our quest to understand life. In addition, radiation of varying levels is assumed to have varying effects on the development and evolution of life. Knowledge of the effects of radiation and gravity on lower organisms, plants, humans and other animals (as well as elucidation of the basic mechanisms by which these effects occur) will be of direct benefit to the quality of life on Earth. These benefits will occur through applications in medicine, agriculture, industrial biotechnology, environmental management and other activities dependent on understanding biological processes over multiple generations.

A third component of Astrobiology includes the study of evolution on ecological processes. Astrobiology intersects with NASA Earth Science studies through the highly accelerated rate of change in the biosphere being brought about by human actions. One particular area of study with direct links to Earth Science is microbe-environment interactions. These interactions can be seen in carbon cycles and nitrogen cycles. Some examples of rapid changes that affect these microbial processes are increases in UV, increases in average and seasonal temperatures, and changes in the length of the growing season, all which are key issues in both Earth Science and Astrobiology. Additional areas include Controlled Environment Sustainability Research (CESR), growth chambers and monitoring capabilities. This research requires unique instrumentation and information science technologies that are not covered in the Earth Science program.

NASA seeks innovations in the following technology areas:

Mobility/Sampling/Subsurface Water Detection Systems

- Innovative techniques that meet these needs are required, e.g., for Mars exploration, technologies that would enable the aseptic acquisition of deep subsurface samples, the detection of aquifers, or enhance the performance of long distance ground roving, tunneling, or flight vehicles are required. For Europa exploration, technologies to enable the penetration of deep ice are required. Desirable features for both Mars and Europa exploration include the ability to carry an array of instruments and imaging systems, to provide aseptic operation mode, and to maintain a pristine research environment.
- Low cost lightweight systems to assist in the selection and acquisition of the most scientifically interesting samples are also of significant interest.
- High sensitivity (femtomole or better) high resolution methods applicable to all biologically relevant classes of compounds for separation of complex mixtures into individual components.

Analytical Tools

- High sensitivity (femtomole or better) characterization of molecular structure, chirality, and isotopic composition of biogenic elements (H, C, N, O, S) embodies within individual compounds and structures.
- High spatial resolution (5 angstrom level) electron microscopy techniques to establish details of external morphology, internal structure, elemental composition and mineralogical composition of potential biogenic structures.

- Innovative software to support studies of the origin and evolution of life. The areas of special interest are (1) biomolecular and cellular simulations; (2) evolutionary and phylogenetic algorithms and interfaces; (3) DNA computation; and (4) image reconstruction and enhancement for remote sensing.
- Nondestructive structural characterization of micro-areas of microsamples of rocks and minerals by diffraction (1-100 micron scale).

Tools to Support Gravity and Radiation Studies of Biological Systems over Multiple Generations
These technologies must be miniaturized to minimize weight, volume and power requirements and must operate autonomously for extended periods of time to accommodate monitoring multiple generations of organisms. Thus, instrumentation must be self-calibrating, require no or minimal consumables and be remotely controlled.

- Biotechnology **-** determining mutation rates and genetic stability in a variety of organisms as well as accurately determining protein regulation changes in microgravity and radiation environments.
- Automated chemical analytical instrumentation for determining gross metabolic characteristics of individual organisms and ecologies, as well as chemical composition of environments.
- Imaging technology with high resolution and low power requirements.
- Habitat support **-** technologies for supporting miniature ecosystems isolated from their support environments, data collection and transmission technologies in concert with the automated chemical instrumentation described above. Candidate technologies include sensor and telemetry systems as well as variable-spectrum, low power light sources for simulating conditions on the early Earth.
- Algorithms for processing and analyzing recovered data.

Instrumentation and information technologies to support the study of evolution of ecological processes and CESR are:

- Miniature to microscopic, high resolution, field worthy, smart sensors or instrumentation for the accurate and unattended monitoring of environmental parameters that include, but are not limited to, solar radiation (190-800 nm at <1nm resolution), ions and gases of the various oxidation states of carbon and nitrogen (at the nanomolar level for ions in solution and at the femtomolar or better level for gases), in a variety of habitats (e.g., marine, freshwater, acid/alkaline hot springs, Antarctic climates or boreholes into the Earth).
- High resolution, high sensitivity (femtomole or better) methods for the isolation and characterization of nucleic acids (DNA/RNA) from a variety of organic and inorganic matrices.
- Mathematical models capable of predicting the combined effects of elevated pCO_2 (change in CO_2 over the eons) and solar UV radiation on carbon sequestration and N_2O emissions from experimental data obtained from field and laboratory studies of C-cycling rates, N-cycling rates, as well as diurnal and seasonal changes in solar UV.
- Microscope DASI (Digital Array Scanning Interferometer) or its equivalent to study soil cores, microbial communities, pollen samples, etc., in a laboratory environment for the detailed spectroscopic analysis relevant to evolution as a function of climate changes.

18.03 Diffractive Optics: Design and Fabrication Techniques
Lead Center: MSFC
Participating Center(s): GSFC, JPL

New and innovative design tools, techniques and fabrication methods are needed to fully exploit the inherent possibilities of diffractive optics to reduce size weight and costs in optical systems and components. Areas of interest include:

- Generalized design software for kinoform diffractive optical elements with applications toward direct write electron beam-lithography, or photolithography fabrication techniques.
- Design and modeling methodologies software for multilevel sub-wavelength structures.
- New low cost fabrication methods for producing diffractive optic elements.
- High aspect ratio structures electron beam lithography fabrication techniques.

- Metrology techniques for high aspect ratio (>3:1) sub-micron structures.
- Large aperture, with sub-micron feature size, diffractive optic fabrication techniques.
- Innovations are sought in using analog spatial light modulators (SLMs) as diffractive optical elements for the control of light. Application areas in which analog devices and methods might be applied include spot generation for directing light waves to disparate destinations, active optics for dynamic correction of environmentally induced aberrations, spatial (rather than angular) addressing of optical memory, and compact and simple display of dynamic image information.
- Large area (>2cm squared) blazed diffractive optical element deposited on a curved surface with optical power for remote sensing computed-tomography imaging spectrometers in the visible and infrared.
- Design and fabrication of diffractive optics for multi-wavelength operation. These could be elements that are useful for wavelength demultiplexing of white light passively illuminated scenes and/or for specialized spectrometry applications.
- Diffractive optics for use in compact, lightweight instrumentation.

18.04 Microwave, Millimeter and Submillimeter Sensing Technology
Lead Center: JPL
Participating Center(s): GSFC

Many NASA future astrophysics, space science, planetary and atmospheric remote sensing programs and missions require microwave to submillimeter wavelength capability. There are current needs for spectrally pure radiation sources for heterodyne applications through 10 THz, novel lightweight diffraction limited antenna systems, low loss THz optics, large bandwidth transmitters and receivers in the 3 cm to 30 micron wavelength range. Pressing requirements are for 1) heterodyne sources in the 0.5 to 3 THz region; 2) very low power backend spectrometers; and 3) broad banded sources with 50+mW output in the 60-200 GHz range. More long-term requirements are for radiometer system components that can be integrated into very small, low cost, low power receiver systems and millimeter wave very large bandwidth/data rate transmitter and receiver systems. There is also interest in high resolution submillimeter wavelength technologies applicable to imaging array receivers.

The focus is on low cost durable technology for application on rocket, balloon and aircraft platforms and at remote/autonomous observatory sites. The technology should also have high reliability with the potential for adaptation to space applications with lifetimes of 5 years or more. The possibility of cooled operation should be evaluated since many Earth remote sensing receivers typically operate near LN_2 temperatures and astrophysics receivers are often cryogenically cooled to liquid helium or lower temperatures to achieve near quantum-noise-limited performance.

For the heterodyne remote sensing systems, there is an emphasis on 1) broad band (>10%) tunable sources with at least a few micro-watts output in the 1 THz to 10 THz frequency range; and 2) 120-1200 GHz sources capable of delivering >20% bandwidth and 100+ micro-watts of power with less than 6 watts DC input. Additional source needs include 1) broad band (>20%) high power (20+mW) active multipliers (x2 and x3) above 60 GHz; and 2) broad banded (>20%) solid state sources capable of generating 50+mW in the 40-300 GHz frequency range. Preference will be given to fundamental oscillator sources. All of the sources should be phase lockable and should be able to achieve less than 25 kHz line width below 1.2 THz and less than 100 kHz line width above 1.2 THz. In addition to the source needs, the long-term goal of this effort is to be able to build complete MMIC heterodyne receivers. Special attention will be paid to higher-frequency and higher-output power MIC and MMIC technology.

The specific needs are as follows:

- Broad band (10-20+%) low power solid state local oscillator sources capable of delivering 100+ microwatts CW in the 120-1200 GHz region and 1+ microwatt CW in the 1.2-10 THz region. Broad band mixers suitable for use in very sensitive heterodyne receivers have been developed in this frequency range and are currently limited by the availability and performance of the local oscillators. A single local oscillator source that could tune over any significant portion of the 1.2-3 THz band with a few microwatts of power output would find immediate use in several different programs. Preference will be given to fundamental frequency sources that require less than 30 W of dc input power and could be used in long lifetime applications.

- Robust, compact, solid-state, phase-lockable oscillator or active multiplier sources with 50+ mW and 20+% bandwidth in the 60-120 GHz range.
- Very compact low power high efficiency sources that could be integrated into MMIC receiver systems and imaging arrays in the 120-300 GHz frequency range.
- Heterodyne receiver integration at the circuit and/or chip level is needed to extend monolithic microwave integrated circuit (MMIC) capability into the submillimeter regime. Integration of all or part of the local oscillator, multiplier chain, mixer, and intermediate frequency amplifier is one example. There is a specific need to demonstrate radiometer systems using phased arrays and MMIC LNA (Low Noise Amplifier) radiometers from 60 GHz to 300GHz or higher. There is also a need to demonstrate arrays of high performance radiometers for imaging through 1.2 THz.
- Compact and reliable millimeter and submillimeter instrumentation that produces low noise images simultaneously in multiple spectral bands.
- Low power multi-channel spectrometers (receiver back-end) that analyze intermediate frequency signal bandwidths as large as 20 GHz with a frequency resolution of <1 MHz, that are small and lightweight, and that use low power (<4 mW per channel) with high stability and lifetimes greater than five years.
- Lightweight and compact radiometer calibration references covering the 100-1000 GHz frequency range.
- Lightweight, field portable, and compact radiometer calibration target references covering frequencies up to 1000 GHz. The reference must be temperature stable to within 1 Kelvin, with a minimum of 3 temperature settings between 250 and 350 Kelvin.
- Low cost special purpose ground-based receivers to detect signals radiated from satellites that are already in space for estimating rain rate, atmospheric water vapor and cloud liquid water.
- Very large bandwidth/high data rate millimeter wave transmitters and receivers for the next generation of Earth to space-based communications.
- Active and passive cooling technology for sub-mm receivers to cool both the receiver and the receiver optics.
- Cryogenic detectors and electronics, including HT superconducting detectors (bolometers, etc.).
- Tunable optical and RF filters for use in cryogenic systems.

18.05 MEMS and Meso Scale Processes and Devices for Instrument Systems
Lead Center: JPL
Participating Center(s): none

NASA urgently requires miniature instrument systems and their components which will significantly impact the overall size, mass and power requirements of both robotic and human missions. This subtopic specifically solicits proposals for devices and instruments that utilize micro-electro-mechanical systems (MEMS) or meso scale fabrication techniques to produce devices of a corresponding size. This subtopic addresses the application of MEMS or meso scale fabrication technologies for in-situ micro-instruments which are capable of operating in space and planetary environments under stresses that might include severe heat, cold, vacuum, high impact, and radiation.

Research instrumentation is needed for fundamental studies of basic phenomena, design code validation, and experimental tests in aerospace facilities such as combustion labs and drop towers. Of special interest are techniques that quantify multiple parameters at multiple spatial points to provide 2D and 3D data in turbo-machinery, around airframes, and in microgravity fluids. Time history data is also important. Fluid parameters of interest include temperature, pressure, density, velocity, chemical composition, viscosity. Surface parameters of interest include temperature, pressure, strain, deformation, and defect detection.

Innovations in miniaturization are desired not only in sensors (e.g., motion, chemical, biological, geological, environmental, electromagnetic, spectral, spatial, etc.), but also in enabling technology such as: vacuum pumps; micro power systems, thermal and power management; packaging; sample collection and processing; and mechanisms for deployment and mobility of sensors and antennae.

The recent increase in emphasis on biological and chemical in-situ analysis and the requirement for drastic reductions in size, weight and power consumption of spacecraft and instruments, creates an opportunity to propose ultra-miniaturized instruments which might utilize combinatorial methods (e.g., arrays of thin film sensors), spectroscopic tools (e.g., Raman spectroscopy, gas chromatography, capillary electrophoresis, mass spectroscopy) or miniature suboptical microscopy (e.g., scanning electron or atomic force microscopes).

Preparation for the human exploration of Mars has been established as a NASA priority. Accordingly, we also solicit MEMS or meso-scale micro-instruments designed to measure and monitor habitability, to control in-situ resource utilization facilities, or to facilitate communication and mobility on the Martian surface.

The next generation of spacecraft will use deployable structures for many purposes such as antennas, solar sails, and telescopes. Micro-instrument concepts will be entertained for sensing structure motion and control such as distributed sensor arrays for smart materials applications.

18.06 Spectroscopic and Multispectral Imaging Sensors in the UV to Far IR
Lead Center: JPL
Participating Center(s): ARC

Advances in state-of-the-art imaging, multispectral imaging systems, and spectroscopic systems in the wavelength region from 10 nm to 1 mm are sought. This includes detectors, readout electronics, and technology for the conversion of electromagnetic radiation to an electrical signal, and the conditioning and transmission of the signal from the focal plane array. Innovations that result in significant reduction of instrument mass, volume, power or data rate with simultaneously improved scientific return are of particular interest. Of special interest are technologies that benefit NASA's emerging Origins thrust, including large format, high sensitivity arrays with stable performance and radiation tolerance covering the 0.5-20 micrometer range; hybrid IR arrays (including novel intrinsic, extrinsic, and bandgap-engineered materials; InGaAs detectors; quantum well infrared photodetectors, and higher-temperature or uncooled infrared focal-plane arrays); and long wavelength IR detection systems with ultra-low noise, with the goal of single photon counting. The following technology innovations are sought:

- Readouts for deep-cryogenic detectors with low noise, low leakage and reduced focal plane power dissipation. Cryogenic technologies of interest include cryo-CMOS, GaAs, germanium, and superconductors.
- Sensor readout electronics with emphasis on low power, single-chip imaging systems, optical readouts and couplers, readouts for high background, long wavelength detectors, high-speed, large format arrays for optical communication in visible and IR. Advanced readout systems with on-chip signal processing such as on-focal-plane digitization with high resolution (14 bits dynamic range), dynamic range management, and specialty imagers such as star trackers, fringe counters, and sensors for wave-front correction.
- Robust and highly sensitive UV detectors in large format arrays. Single photon counting is a goal, and solar blindness is a significant advantage.
- Detector/array calibration and characterization techniques, particularly for challenging applications in extremely low signal/background environments.
- Solid state polarimeter detectors including both linear and full stokes vector devices.
- Linear photon counting arrays emphasizing wavelengths at 355, 532, and 1064 nanometers (e.g., Geiger Mode APD).

19 Distributed Spacecraft

Virtual platforms and distributed spacecraft control technologies will revolutionize the manner in which Earth and Space Science missions are conceptualized, planned, designed, and implemented. This thrust area seeks new concepts, approaches, and strategies that enable higher levels of interaction between vehicles, cooperation between vehicles, and the ability to function with a common system wide capability. Distributed networks of individual vehicles will replace large complex observatories. They will operate under virtual infrastructures capable of responding to changing needs and conditions and evolving over time to introduce new capability and technology. Extensive co-observing campaigns, coordinated multi-point observing programs, significant improvements in space-based interferometry, and entirely new approaches to conducting Earth and Space Science will be achievable while reducing the complexities, costs, and schedule requirements associated with traditional mission concepts. This topic focuses on the guidance, navigation and control aspects of multiple distributed assets or space vehicles, including architectures, methodologies, and hardware components. Distributed networks include all types of multiple cooperating space vehicles, e.g., balloons, instruments and detectors, mirrors and satellites. As a secondary focus, technologies which are critical to the end-to-end distributed spacecraft system are requested and include onboard autonomy; integrated micro/nano avionics; systems for reducing reliance on ground operations for tracking, command and control, and asset management; propulsion systems to support rapid mobility/reconfiguration and control of assets; and tools for distributed observation data collection, archiving, dissemination and analysis.

19.01 Autonomous Guidance, Navigation, and Control for Aerospace Systems
Lead Center: JPL
Participating Center(s): GSFC, LaRC

Proposals addressing the following technology requirements for autonomously operating aerospace systems are sought:

- Advanced architectures, algorithms, and software for high precision autonomous control of formation flying spacecraft.
- Control systems which may utilize, but are not limited to, fuzzy logic, neural networks, discrete-event system methods, etc., that are capable of autonomously monitoring spacecraft functions and environmental conditions, assessing health status, and optimizing system performance through in-flight identification, fault detection, stabilization, and re-configurable control techniques.
- Parallel algorithms to better manage complex tasks required for guidance and control of multiple vehicles in a distributed network.
- Guidance and navigation methods for multispacecraft proximity operations in Earth orbit based on the use of GPS or other RF signals.
- Techniques for the control and steering of multiple robotic balloons for coordinated flight.
- Fleet management technology including the re-optimization of assets to target newly identified concerns or events and the ability to move or re-point the fleet in a timely manner; and the deployment, initialization, maintenance, reconfiguration, and on-orbit repair and upgrade of the fleet.
- High precision guidance, navigation and control constellation sensors including optical, celestial, and RF.
- Autonomous onboard guidance and relative navigation techniques with position accuracy requirements on the order of sub-meters with control sensitivity to sub-millimeters and pointing requirements on the order of sub-arc-seconds. Navigation techniques can utilize, but are not limited to, GPS and the Wide Area Augmentation System (WAAS).
- Advanced computer-aided engineering and design tools for the control of a distributed network of multiple space vehicles. Innovative testbed development capabilities in the area of computer and dynamic simulation of multiple satellites using spacecraft processors to communicate and maintain the formation. Tools should allow faster trade studies, cut analysis costs, allow quick prototyping of flight software, and provide reliable interpretation of real-time simulations.
- Mission analysis and design tools, simulation tools, and testbed environments to support the development, verification, demonstration, and application of distributed spacecraft techniques. This includes techniques for the high fidelity modeling and simulation of the interaction of distributed spacecraft in support of crosslink communications, navigation, and distributed autonomous control methodologies. Six-degree-of-freedom platform coordination is desired.

20 High Rate Data Delivery

All NASA missions rely on the transmission of data for their successful completion. NASA develops innovative data systems and communications technologies for its own use and collaborates with U.S. industry in the development of technologies that have the potential to satisfy NASA and commercial system needs. Since portions of the transmission paths for future missions will use commercial satellite networks, the technologies sought here may find application on either NASA or commercial satellites in satisfying NASA's unique requirements. To fulfill these goals, NASA conducts a program of research and technology at the device, subsystem and system level in such areas as onboard data collection, processing and storage; microwave, millimeter wave and optical communications; digital processing, modulation and coding; communications architectures, networks and system protocols. Among technologies solicited in these subtopics are those which will significantly enhance the processing, storage and transfer of data from the sensor to the user.

20.01 RF and Optical Communications for Earth Satellites
Lead Center: GRC
Participating Center(s): JPL

Innovations are sought for application to commercial satellite communications and NASA missions. Advanced techniques and products (radio frequency and optical) are invited that support commercial low, medium, and geostationary Earth-orbiting (LEO, MEO, GEO) satellite networks for integrated, fixed, transportable, and mobile broadcast and/or wireless communications and information services. Innovations are expected to offer significant improvements in performance, weight, power efficiency, reliability and/or cost. Products are sought in the following areas:

- Latency-tolerant data communication protocols and enhanced Asynchronous Transfer Mode (ATM) and related network technologies for interoperable space-terrestrial networks. Data protocols for LEO/MEO networks.
- Internet technologies to provide information transfer from space via satellite networks directly to the users. Innovative approaches to software simulation tools for rain fade compensation and for evaluating space-based networks.
- Software/hardware technologies to enhance configuration management, performance monitoring, fault isolation and security of data communications networks involving satellite links integrated with terrestrial networks.
- Low cost, Ka-band flat plate array antennas, 2 watt Ka-band, MMIC power amplifiers and low noise block down-converters for USAT applications. Low cost, precision tracking Ka-band Earth terminals for high data rate (OC-3 to OC-12) direct-to-Earth downlinks from LEO/MEO spacecraft.
- Wide scan angle (+/- 60 degrees), low profile, transmit/receive Ka-band antennas, Ku-Ka band transceivers and closed-loop acquisition/tracking algorithms for aeronautical communication satellites.
- Novel materials and computer-modeling techniques are required to enable higher frequency, lower mass travelling wave tube amplifiers (TWTA) operating at 20, 28-32, 60 and 94 GHz for satellite communication and radar mapping missions. Of particular interest is the development of TWTAs that can operate at communication bit rates of 10 Gbps or higher.
- As NASA drives the size of satellites smaller while increasing the functionality of the system, new technologies are required. Micro-electro-mechanical Systems (MEMS) applied to RF circuits are envisioned as one technology that would enable this to happen. Therefore, MEMS-based RF switches with insertion loss less than 0.1 dB at 20 GHz and high isolation are required. In addition, MEMS that would enable the development of reconfigurable antennas and filters for in-flight control of the radiating frequency, bandwidth and power are required. Another technology that would enable the next generation of satellites is the development of analog to digital and digital to analog (A/D and D/A) converters operating at 10-20 Gbps. These high data rate circuits would be used to replace RF analog communication circuits. A possible technology for high data rate circuits is the SiGe HBT's and MODFET's. Finally, RF component and sub-system technologies are required that increase the level of integration above the current state-of-the-art to enable "system-on-a-chip" type

communication systems. Requirements include materials, processing methods and modeling of RF multilevel interconnects, circuits and packages.

- Power and bandwidth efficient modems, combined modulation and coding schemes and digital transmission techniques for application in NASA communication links, space- or ground-based. Higher order modulation schemes, combined with powerful coding techniques to maintain compatibility with standard terrestrial data rates with QoS of 10-9 bit error rate or better. Innovative approaches to reduce size, mass, power and cost; single chip integration of multiple functions; use of digital technologies to enable multi-Gigabit/second throughputs.
- Innovative application of highly reliable and efficient onboard processing (OBP) technology and switching and routing schemes necessary to achieve a 10 to 100 times improvement in capacity. Novel OBP architectures and multiple access methods addressing throughput blocking, queuing delay, cost, complexity and reliability are sought.
- Novel system designs and advanced optical technologies are needed to enable efficient ultra high data rate communications on space-to-space, space-to-ground and/or ground-to-space links for GEO or non-GEO satellite networks. Areas of interest include lightweight, low cost and thermally stable telescopes; efficient, high power (>1W) semiconductor diode lasers and arrays; high bandwidth modulators and detectors; techniques to mitigate the effects of atmospheric attenuation/turbulence and methods to reduce mass, power and complexity of the acquisition/tracking/pointing process.

20.02 RF and Optical Communications for Deep Space Missions
Lead Center: JPL
Participating Center(s): GRC

NASA's goals for future interplanetary missions require advances in higher-capability, smaller, and more power-efficient spaceborne telecommunications. Due to the enormous distances from Earth, design of these systems imposes unique challenges for transmitter sources with higher effective isotropic radiated power (EIRP) and higher receiver sensitivities, while maintaining low power consumption and low system mass. Technology options being considered include improved radio frequency and optical communication systems. Additionally, sensors being planned for future Earth-orbital missions will produce significantly higher data rates as well. For these missions, the limitations on communications come not from physics, but from limits on RF spectrum allocation. To circumvent this limitation, NASA is developing high-data-rate laser communication systems. Data rates up to several Gbps can be transmitted from Earth-orbit-to-ground, or via space-space relay.

For optical communication systems, innovative concepts are solicited for space-based applications in the following areas:

- High-speed, high quantum-efficiency, very low noise FPA's (e.g., CCD, APS, HIT, CID) with large field of view (> 5 mrad) and small pixel sizes (< 20 micron). Also interested in infrared (1 - 2 micron) FPAs.
- Focal-plane-array detectors with built-in (on-chip) processing and/or focal plane arrays combining redundant CCD and QAPD sensors.
- High-power, highly efficient, space-qualifiable, lightweight, diode lasers, diode-pumped lasers and fiber lasers with good beam quality.
- Highly efficient diode lasers at 1550 nm with greater than 4 W output power and bandwidths to 1 GHz.
- High-speed (equal to or greater than 1.0 GHz) diode-laser drivers and/or modulators for capable of handling more than 200 milliwatts of output power with low insertion loss.
- Power-efficient modulation and coding systems.
- Acquisition, tracking, and pointing techniques that reduce mass, power and complexity.
- Lightweight, low power, two-axis, mechanical and non-mechanical beam steering devices with steering ranges greater than 1 degree.
- Optical phase-control devices.
- Narrow-band (0.1 to 1.0 angstrom), high-throughput (more than 0.60) optical filters.
- Optical filters with greater than 80% transmission and better than 10 dB/nm roll-off in the near-IR band.
- Ultra-lightweight, baffled, thermally stable diffraction-limited telescopes.
- Lightweight stray-light control concepts.

Also of interest for optical free-space communication are technologies to enable low cost ground reception systems including:

- High-efficiency, high-speed, optical detectors and detector amplifiers. Also highly efficient, integrated detector amplifiers with bandwidths greater than 1 GHz and large optical signal collection diameters at 0.8-1.6 micron wavelength.
- Clock and data signal recovery assemblies with 20 dB input signal dynamic range and update dates of 1 kHz.
- Ultra-narrow-band (0.01 to 0.5 angstrom) optical filters.
- Low cost 1-m diameter optical telescopes that can accurately track Earth-orbiting satellites.
- Innovative concepts for low cost telescope mounts and enclosures.
- Low cost optical telescopes (photon-buckets) from 3 to 10 meters in diameter.
- Adaptive-optics systems to mitigate the effects of atmospheric turbulence.

Areas in RF communications where innovations are sought include:

- Modulation and coding techniques and network designs for deep-space communications that reduce cost, spacecraft power and mass, bandwidth and operations requirements.
- Ultra-small, low cost, low power, deep space transponders and components, including low-voltage, high-efficiency integrated circuits such as microwave monolithic integrated circuits (MMICs) and MMIC filters. Signal processing circuits for receivers that provide carrier tracking, command and ranging capabilities. Low-voltage, multi-function MMIC designs with integrated filters to provide low-noise down-conversion, automatic gain-control, up-conversion, and transceiver functions at Ka-band (32 GHz). MMIC modulators to provide large linear phase modulation (above 2.5 radians), high data rate BPSK/QPSK modulation at Ka-band. Miniature, ultra-stable and voltage-controlled oscillators for deep space communications and GPS applications. Miniature, low-loss X-band (8.4 GHz) and Ka-band switches and diplexers.
- Miniature, high-efficiency power amplifiers and RF power devices operating in the X- or Ka-band, transmitters with output power levels ranging from 3 watts to 20 watts, and both innovative solid-state as well as thermionic devices that can survive the space environment with mean-time-to-failure of 10 years or more. MMICs supporting miniature, high-efficiency power amplifiers at Ka-band (primary focus) and X-band (secondary focus) such as gain blocks, multi-bit digital phase shifters and power cells. Support elements like low-loss, miniaturized isolators, high-efficiency integrated DC-DC power converters, and miniaturized power dividers and combiners. Advanced packaging concepts and techniques for the packaging and miniaturization of high-efficiency power amplifiers at X- and Ka-band.
- Low-mass, high-gain, high-efficiency antennas typically with diameters less that 2 meters, integral with spacecraft surfaces, or that can be reliably stowed in low volumes.

21 Thinking Space Systems

This topic seeks to provide adaptive, inquisitive, self-reliant, self-commanding systems able to operate autonomously in a changing and uncertain environment. These systems will accept high-level goals as well as low-level command sequences. They will be able to conduct further measurements or activities based on current or historical observations or inputs, recognize desired phenomenon and concentrate observations or activates accordingly, and monitor and maintain desired status configurations for long periods of time without frequent communications with ground systems.

21.01 Automated Reasoning for Autonomous Systems
Lead Center: ARC
Participating Center(s): GSFC, JPL, JSC

NASA is planning to fill space with robotic explorers, carrying our intelligence and our curiosity, to explore the universe beyond in ways never before possible. To survive decades of operation, these remote agents need to be smart, adaptable, curious, wary, and self-reliant in harsh and unpredictable environments. NASA is soliciting research in automated reasoning for autonomous systems that will enable the design, construction and operation of a new generation of remote agents that perform progressively more exploration at much lower cost than traditional approaches.

To achieve ambitious exploration goals, researchers must develop autonomous control kernels that can be commanded by simple, high-level, goal-directed behaviors, such as "make an attitude determination followed by a course correction". These mechanical explorers will be programmable through compositional, commonsense models of hardware and operations behavior. This model-based programming paradigm will allow control systems of spacecraft to be plugged together like Lego blocks from libraries of existing models, and will permit novel behaviors to be programmed in a simple intuitive manner. Using these models onboard, the automaton will close the loop on sensor information at the goal level, using advanced deductive planning and execution, scheduling, diagnosis and recovery capabilities to ensure that goals are being met. This goal-directed, model-based programming paradigm is already beginning to emerge through systems like the Deep Space One Remote Agent Architecture.

Achieving capable intelligent robotic explorers will also require systems that learn from their interactions with their environment and adapt in real-time, by using model-based deductive methods to help coordinate and direct collections of biologically inspired adaptive methods. The remote agents will need to be curious and wary, requiring capabilities for taking action to gain information, assessing risk, planning contingencies and preparing backup resources, or redirecting plans to reduce risk. Finally, these automaton will often act as teams, requiring significant distributed coordination and collaboration capabilities.

Specific areas of interest for automated reasoning include the following:

Remote Agent Architectures
- Architectures for onboard operation that support goal-directed commanding, model-based programming, and the plug and play of automated reasoning components.
- End-to-end architectures that provide a seamless coupling of automated reasoning capabilities for flight and ground operations, and that support easy migration from ground to flight.
- Single and multi-agent architectures which allow the level of autonomy to be easily, precisely and dynamically adjusted.
- Architectures that use automated reasoning to coordinate intelligent design synthesis and science opportunity analysis.

Planning, Scheduling and Resource Management
- Planning and scheduling systems that use component-based models to support plan generation and dynamic replanning concurrent with execution.
- Advanced planning and scheduling systems that support any-time generation of flexible plans, goal-prioritization, resource optimization, contingency, and sensor-based, iterative and adaptive planning.
- Centralized and decentralized methods for generating plans by coordinating a heterogenous set of special purpose planners.

Executives
- Goal-directed systems for plan and command sequence execution.
- Procedural executives with services for configuration management, resource management and plan running.
- Model-based executives that perform significant deduction within the reactive control loop, and hybrid procedural/deductive executives.
- Distributed, muli-agent execution capabilities.

Fault Protection and Model-Based Reasoning Systems
- Model-based and statistical methods for monitoring, command confirmation, fault isolation, and diagnosis from sensor information.

- Model-based reasoning and planning methods for robust recovery and repair, including establishment of a safe operating state as a minimal goal, and preservation procedures from models.

Reasoning Kernels

- Algorithms for high performance deduction and search in real-time, including anytime, systematic and stochastic search algorithms and incremental truth maintenance systems.
- Methods for efficiently abstracting, approximating and compiling models.
- Decision theoretic and adaptive reasoning kernels.

Large-Scale, Declarative Modeling and Software Engineering Environments

- Unified languages for model-based programming and declarative specification of software and hardware behaviors.
- Collaborative environments for large-scale model building, specification and reuse. Methods that operate on these declarative models/specifications include document generators, visual debugging environments and automated modeling algorithms.
- Advanced techniques for process support, requirements engineering and reverse engineering.
- Methods for code synthesis and controller generation from declarative specifications and models.
- Tools for automatically generating high-fidelity, fault injection from component-based models.
- Automated generation of test sequences from component models, and analytic verification methods, including model checking and theorem proving.
- Methods for modeling, code synthesis, simulation, testing and validation, as above, that operate from hybrid discrete/continuous models.

21.02 Human Centered Computing
Lead Center: ARC
Participating Center(s): none

Human-centered computing, an approach to the design and implementation of computer systems, seeks to integrate computational systems with human performance and capabilities, such that the total system amplifies, corrects, and leverages the capabilities of both people and machines. Aerospace missions, including the human exploration of space, combine a high degree of automation with often-unique system complexity and substantial risk to human lives. The design of computer systems necessarily must take into account not only how people will "interface" with the systems, but fundamental aspects of human perceptual-motor coordination, cognitive operations, and group dynamics. Human-centered computing focuses on the "delta" that respects the particular contributions of humans and machines, designs machines and operational procedures to complement each other, and exploits the understanding of the differences between people and machines to build more capable computer systems. To advance along these lines, proposals are sought in the following areas:

- Advanced AI systems/architectures for mixed-initiative system planning, monitoring, and control, with provision for crew oversight. Architectures that have predictable behaviors, leave people in control, and expose their workings in ways comprehensible to people with different skills.
- "Cognitive prostheses" that qualitatively change the capabilities of human perception, pattern analysis, scientific domain modeling, reasoning, and collaborative activity. Such tools could incorporate any of a variety of modeling techniques such as knowledge-based systems and neural networks, and fit tool operations to ongoing human physical interaction, judgment, and collaborative activity.
- Information technology enabling comprehensive sharing of project-related information and data, which supports intelligent organization, access, and presentation of the information. Particularly, tools that fit the human activities of scientific inquiry and engineering design, and relate the contributions of individuals to the developing plans and products of teams.
- "Knowledge management" tools that relate technical models of human knowledge to: a) nonverbal concepts and perceptual skills; b) the daily activities of workers, including especially how databases are actually used in practice; c) informal on-the-job learning; and d) the career trajectories of novices, experts, and retiring employees.

- Agent-based tools for information gathering, reminding, and alerting; job performance aids that provide cognitive assistance in the context of the daily activities and interests of operations personnel and crew.
- Communication technologies and software tools that enable mission control teams to work together when they are located at different sites and working on several projects.
- Tools for software requirements analysis that incorporate and relate models of databases, legacy systems, and work practices.
- Workflow systems that allow teams of users to formalize and routinely reconfigure their own document templates, processing categories, operating procedures, and archival records.
- Software systems that provide specialized support for collaborative science and engineering tasks, including design, data collection, experimentation, analysis, and model construction to enable scientists and engineers to collaborate as part of distributed project teams at physically separate sites.
- Computing architectures that address the limitations of knowledge-based systems and neural networks, relative to human capabilities, advancing the state-of-the-art in automated perceptual categorization, non-verbal conceptualization, and coordination across multiple sensory modalities. Applications might include planetary probes and rovers with new kinds of instrumentation, signal processing, and sensing-through-movement.
- Visualization tools combining "virtual reality" projection with actual objects in the environment, conveying information about object identity, part relationships, and assembly or operational procedures.

21.03 Data Understanding and Adaptive Methods
Lead Center: JPL
Participating Center(s): none

NASA now collects terabyte-scale datasets routinely from its missions, and charges the scientific community with extracting usable and scientifically relevant information from them. These datasets may be planetary or stellar images, multi-spectral images, or field and particle event-lists. They may also be engineering time series about spacecraft health collected from onboard sensors. In addition to the ongoing challenges entailed by handling, analyzing and mining very large data sets in archives, NASA now also needs a new framework for performing science data evaluation onboard spacecraft. The future NASA mission set will feature smaller and more numerous spacecraft in an environment of highly constrained uplink and downlink communications requiring substantial onboard intelligent computation to achieve its goals. New onboard science capabilities will enable mission activities to be directed by scientists without the assistance of a ground-sequencing team, robust capture and redirection in making discoveries at the target body, accommodation of the realities of constrained communication links, and the continued return of quality science products from missions.

Through onboard decision-making, scientist-trained recognizers, and judicious use of knowledge discovery methods, a portion of the scientist's awareness can be projected to the space platform, providing the basis for scientist-directed downlink prioritization and the processing of raw instrument data into science information products. This software-based partnership between scientist and space platform can evolve during the mission as the scientist becomes increasingly comfortable with the direct relationship with the space platform, intermediate scientific results emerge, and scientist-directed software updates are uploaded. This subtopic enlists help in developing a new generation of tools and algorithms for effective acquisition and analysis of data and image sets, appropriate for ground or onboard use. Of special interest are: (1) the ability to deal quantitatively with uncertainty present in data, perhaps in a statistical framework; (2) development of flexible models through which observables are linked to quantities of scientific or engineering interest; (3) harnessing database technology for organizing the observed data, models, and inferred knowledge, perhaps in onboard archives; and (4) system concepts for handling interactions between onboard science analysis and event detection capabilities and other functions of an autonomous spacecraft. One or more of these areas should be addressed by every proposal. Specific technical topics of interest include:

- Automated classification of data.
- Supervised and unsupervised learning methods.
- Knowledge discovery techniques.
- Image analysis and segmentation.

- Statistical pattern recognition.
- Time-series feature extraction and analysis.
- Trainable object recognition.
- Automatic image registration and change detection.
- Spatiotemporal data mining.
- Automated planning of image and data product generation.
- "Intelligent" (goal-directed) data acquisition and/or compression.
- Science data analysis algorithms designed for scalable computing.
- System concepts for onboard science.

22 Spacecraft Miniaturization Technologies

This topic solicits spacecraft technology development proposals in the area of Micro/Nano-Sciencecraft. NASA is moving toward miniature [approximately 1-50 kilogram], low cost spacecraft playing an increasingly frequent and important role in its broad spectrum of planetary, space physics, and Earth Science missions. NASA's intent is to revolutionize the size, technology content, and functionality of future spacecraft in order to enable new science investigations at acceptable costs. Microelectronics and Micro-Electro-Mechanical Systems (MEMs) technology that integrates engineering and science instruments at unprecedented levels into a functioning sciencecraft is an appropriate approach. Innovations are sought that significantly reduce the power, mass, volume and cost of spacecraft through advances in microelectronics, computing technologies, and avionics architectures. All traditional spacecraft subsystems are opportunities for miniaturization. Highly integrated multifunctional and adaptive structures are also encouraged.

22.01 Deep Space Microspacecraft Subsystems, MEMS, and Microelectronics
Lead Center: JPL
Participating Center(s): LaRC

The strategic plan within the Office of Space Science at NASA calls for intense exploration of a wide variety of bodies in the Solar System within a modest budget. To achieve this will require revolutionary advances over the capabilities of traditional spacecraft systems and a broadening of the tool set through the introduction of new kinds of space exploration systems. Microspacecraft systems (as small as 10 kg, 10W, or less) of all varieties will enable new missions that are currently impractical. These systems will include, but are not limited to, orbiters, landers, atmospheric probes, rovers, penetrators, aerobots (balloons), planetary aircraft, subsurface vehicles (ice/soil), and submarines. Also of interest are delivery of distributed sensor systems consisting of networks of tiny (<<1 kg) individual elements which combine sensors, control, and communications in highly integrated packages, and which are scattered over planetary surfaces, atmospheres, oceans, or subsurfaces. New technology is needed in all spacecraft areas for mass, power, and volume reductions, and for application to harsh environments such as extreme temperature, radiation, and mechanical shock. Advances in MEMs, microelectronics and avionics architecture are encouraged.

Applicable technology areas include, but are not limited to:

- Avionics, including highly integrated "systems-on-a-chip" technologies that integrate areas such as telecommunications, power management, data processing and storage, on-chip energy storage, on-chip magnetics or data sensors.
- Micro-Electro-Mechanical Systems (MEMS) including: miniaturized instrumentation sensors, microactuation, navigation sensors, health-monitor sensor systems, low power and low-mass communication systems, and micro propulsion systems.
- Propulsion, including chemical and other techniques, also including techniques for machining/manufacturing ultra small parts, and materials joining technologies for microtubes and mini/microcomponents; lightweight propellant tankage and fluid handling components.
- Thermal management, including active and passive techniques.

- Integration of functions such as engineering sensors and science instruments, structure, thermal, cabling, propulsion, etc.
- Advances in techniques and devices for relay communications through atmospheres, ice layers, soil, and oceans.
- Three-dimensional VLSI, chip stacking, multi-chip-module stacking and other advanced packaging techniques.
- Low power, COTS-based radiation tolerant and advanced power management techniques.
- High performance, low power and low cost subsystem interface.
- Space qualifiable, high density, non-volatile mass memory.
- Fault tolerance and onboard maintenance design and analysis techniques for severely constrained environments and extreme long life missions.
- Concepts and designs for test and validation of design integrity and performance of IP based ASICs, mixed signal ASICs and MEMS.
- High resolution, high sampling rate, low power and radiation-hardened analog-digital converters, and digital signal processing hardware components with algorithm design environments for rapid design and prototyping.

22.02 Multifunctional and Adaptive Systems
Lead Center: LaRC
Participating Center(s): JPL

NASA seeks innovative concepts for multifunctional and adaptive systems to reduce spacecraft size and mass, and to enable lower-cost and more capable aerospace vehicles. A multifunctional system combines several functions, which are usually performed by separate subsystems, into a single highly integrated system. An adaptive system may incorporate sensing, processing, and actuation so that it can respond to changes in its environment, reconfigure its geometry, control its dynamics, or repair itself when damaged.

Potential mission applications for the technology products developed in this area include micro/nano-spacecraft, thin-film gossamer spacecraft, large-aperture telescopes and antennas, and airframes. High-priority technology development needs are:

- Techniques for the structural integration of low-volume electronics packaging such as chip-on-structure, chip-on-flex (flexible substrate), and imbedded electronics.
- Concepts for integrating electronics, power distribution, thermal management, and radiation shielding with ultra-lightweight composite structures.
- Multifunctional membranes that incorporate thin-film electronics and sensors, photovoltaic cells, or electrochromic materials.
- Integration of two or more spacecraft systems functions in miniature components for micro/nano-spacecraft.
- Piezoelectric, electrostrictive, and superconducting actuators that have high displacement resolution, that can hold position without power, and that are capable of operating at cryogenic temperatures for shape control of large telescope mirrors.
- Highly integrated actuator/sensor arrays for high-bandwidth compensation of optical and RF wavefront errors using deformable secondary mirrors and antenna feeds.
- Adaptive and reconfigurable structures that can respond reactively to environmental stimuli for vibration suppression, load alleviation, and self-repair of damage.
- Analytical tools for modeling the dynamic performance of smart structures, including piezoelectric coupling, dynamic response, finite element modeling approaches, and inputs for test conditions.

23 Next Generation Infrastructure

This topic area focuses on the innovative products required for the Intelligent Synthesis Environment (ISE) which is an advanced engineering and science environment for all of NASA's Enterprises in performing life-cycle design and development of all missions, programs and projects. It includes rapid synthesis and simulation tools, cost and risk management technologies, life-cycle integration, methods for seamless tool integration, collaborative engineering and science capabilities, product data management, advanced user interface application, validation and validation methods, and technology forecasting and new-technology infusion predictive capabilities. The ISE supports conceptual design through disposal or mission termination. Developed methodologies may be based on traditional or non-traditional approaches and may be either deterministic or non-deterministic in nature. Particular emphasis is on capabilities that result in design decision tools that incorporate early consideration of detail design, manufacturing, operations and training. All proposals developed under this topic area should address issues related to such items as inter-operability, web accessibility, interfaces between tools, information systems and databases, and adherence to evolving standards.

23.01 Instrument Modeling and Simulation, End-to-End Mission Automation and Autonomy, and Science Knowledge Discovery
Lead Center: GSFC
Participating Center(s): none

NASA's new missions will be noted for dramatically decreased budgets and mission development lifecycles thereby demanding the need to achieve improved mission designs, with fewer resources, in less time. Innovative new automated approaches for managing and analyzing scientific data and information are needed. The continued need to reduce cost of future remote sensing scientific instruments requires innovations in design, modeling, analysis and verification. An integrated, reusable, multidisciplinary, collaborative engineering approach using modeling and simulation tools, multidisciplinary processes and modern information technology is essential.

To achieve these future challenges, advanced information and engineering technologies and systems are sought for infusion and to serve a critical role in the formulation, implementation and execution of space missions. NASA is soliciting technologies supporting these challenges including:

- Efficient, integrated end-to-end instrument modeling and analysis tools for characterizing the performance, parametrically optimizing the design, verifying the design, and for "virtual testing and calibration." This is to include active/deployed optical systems, cryogenic optical systems and microwave/millimeter wave systems.
- End-to-end instrument systems simulation tools for end-to-end system-level optimization and for performing the "virtual experiment." These tools are to include the integration of the scientific measurement phenomena, the operating environment, the ground data processing and the instrument subsystems, especially the optics, electro-optics, opto-mechanics, sensors, signal processing.
- Non-deterministic engineering tools to account for stochastic parameters and to use reliability rather than margin-of-safety for design validation.
- Integrated engineering environments providing single interfaces to a suite of tools and engineering data repositories that cover the life-cycle of mission development.
- Integrated life-cycle science allowing interaction with a specific mission data set at an object domain level.
- Component-based architectures for engineering tool environments providing domain level plug-and-play components.
- Collaborative visualization systems to allow life-cycle end-to-end views of mission development, operations, and disposal.
- Tools, methodologies, and object-models supporting component-based software development for spacecraft missions.
- Goal-driven and event-responsive spacecraft and mission control systems.
- Automated operations and mission management tools especially those supporting health and safety management of a fleet of spacecraft, and enterprise management of science data production and distribution systems.
- Adjustable mission automation and autonomy tools.
- Automated science data synthesis and data management tools for multi-spacecraft constellations, including lossless and lossy data compression.
- Hi-fidelity system modeling and simulation tools and techniques supporting multiple spacecraft/system operations simulation and engineering.
- Spacecraft-based automated planning and activity execution.

- Next-generation space mission planning and scheduling tools for managing resource allocation and conflict resolution of fleets of spacecraft.
- Data mining and other analysis tools for science information discovery.
- Techniques to support information exchange for distributed heterogeneous architectures such as metadata structures or interface protocols.
- Advanced agent-based technologies to support higher levels of spacecraft and ground system autonomy.
- Distributed planning and scheduling among smart spacecraft to support cooperative activities.

23.02 Spacecraft Modeling and Simulation Tools
Lead Center: JPL
Participating Center(s): none

There is a critical and growing need to achieve better spacecraft designs, with fewer resources, in less time. From a mission and system perspective, enhanced performance and reduced cost requires: variable-fidelity modeling and simulation; uniform system information storage; seamless integration of tools and applications; continuity of products through the mission life-cycle; and efficient methods for optimization. Innovations in spacecraft modeling should address issues such as interfacing with collaborative development processes; validation of decisions and products; usage of scalable, open architectures; interface tools that allow efficient creation and modification of mission scenarios with minimal support by software engineers; and methods for collaborative scenario visualization, including advanced displays, language, and adaptive interfaces.

- Spacecraft Modeling and Simulation
  - Creation and capture of variable-fidelity models.
  - Reusability of legacy modeling/simulation/analysis.
  - Subsystem trade analysis for performance, cost, resource utilization.
  - Requirements capture, execution, and tracking.
- Infrastructure for Modeling and Simulation
  - Object modeling languages.
  - Interface for higher-level model integration at the system level.
  - Object-oriented architectures, object instantiation, object brokers.
  - Messaging architectures, e.g., publish/subscribe.
- User Interfaces
  - Scenario creation and selection: graphical and linguistic programming.
  - 2D/3D displays; effectors (manipulation of virtual objects).
- Tools
  - Discipline tools: automation of tool interoperability; tool control languages and mega-programming.
  - Non-deterministic tools: uncertainty prediction for design/analysis; reliability/risk assessment.
- Advanced Product Models
  - Smart product models.
  - Analytical, behavioral and CAD model integration.

23.03 Modeling, Simulation, and Asynchronous Technologies for Life-Cycle Integration, Validation, and Distributed Collaboration
Lead Center: LaRC
Participating Center(s): KSC

The NASA Intelligent Synthesis Environment (ISE) seeks to address all aspects of design development and life cycle management, including the ability to determine complete life-cycle requirements and costs early in the design cycle. There is a critical need for modeling, simulation, and asynchronous technologies that support integration throughout the entire life-cycle of a mission, project, or vehicle (a typical NASA life-cycle is on the order of 30 years). This integrated capability must be supported across diverse geographic, cultural, and computational environments and be used not only in the ISE but within other organizations as well. NASA ISE is focused on designing, delivering, supporting and commercializing advanced technologies, and collections of technologies, that support the advancement of engineering, engineering tools, and engineering methodologies. A goal is the development of tools that support the creation, storage, management, and retrieval of information over entire program life-cycles. Tools and technologies are expected to be de-coupled from the actual data storage elements to facilitate the separate evolution of various technologies. The architecture involved must support preservation of the data as well as operation on the data sets by multiple tools.

There are many emerging technological concepts that show promise as potential ISE technologies. Examples of some existing concepts, which HAVE NOT been incorporated into integrated data life-cycle management are: (1) Intelligent Agents (push/portals/information dissemination); (2) Threaded Discussions/Community of Interest Sites; (3) Data Mining; (4) Project Management Integration; (5) Document Collaboration; (6) Library; (7) Workflow/Status Checking; and (8) Information Compartmentalization to reduce information overload.

Requirements exist for the following areas of interest:

- Software system architectures that enable life-cycle simulation systems to be assembled quickly and tailored for specific vehicles or missions. Such systems must be compatible with legacy software codes as well as permit the insertion of research technology by users.
- Rapid model assemblers technology that enables components and a knowledge base to assist the modeler in providing validated model data suitable for the simulation of the entire life-cycle of a product.
- Software systems and products that reduce the effort required for creating immersive visualization displays of intermediate simulations is necessary to validate the intermediate results. Such systems must be general enough to support the entire life cycle of NASA's diverse missions and vehicles.
- Distributed collaboration tools that support the integration of life-cycle analysis in both modeling and simulation.
- New technologies that allow collection, storage, and retrieval of various forms of integrated data (graphical, text, photo, email, sound, etc.) associated with a process life-cycle (full life-cycle, greater than 30 years).

24 Surface Systems

This topic seeks innovative technologies that significantly improve NASA's ability to explore and colonize solar system bodies. A variety of vehicle systems will explore atmospheres, rugged surface terrains, liquid surfaces, ice, subsurface, and liquid oceans in a wide range of hostile environmental conditions. Innovative vehicle system design and machine intelligence are needed to enable long-term survivability and exploration with communication delays to human operators of days or more. In-situ resource extraction and robotic assistants to astronauts are needed to provide capability for exploration and colonization.

24.01 Robotic Surface and Subsurface Systems and Colonies
Lead Center: JPL
Participating Center(s): JSC

Innovative technologies are sought to support robotic surface and subsurface exploration and colonization of solar system bodies. Advanced mobility and manipulation systems are needed as well as their onboard and ground-based sensing, perception, planning and reasoning systems.

- Microrover (less than 30kg) and nanorover (less than 1kg) related technologies are needed to support planetary surface exploration over rugged terrain. Surface mobility concepts under consideration include walking machines, wheeled rovers, unique suspension systems, hybrid locomotion, and hopping/jumping machines.
- Technologies are needed to support exploration in shallow and deep locations below the surface and underwater.
- Technologies for manipulation from rovers, landers and underwater vehicles are needed.

- Component mechanism technologies to support planetary robots are needed, such as low-mass high-torque actuators, collapsible wheels and structures, legs, and lightweight manipulators and masts.
- Miniature sensors are needed such as stereo cameras, sun-based location sensors, and integrated multi-functional sampling mechanisms.
- Earth-based perception, planning, and analysis technologies are needed to enable distributed planning of resource constrained missions. Scene analysis will assist in localization, task selection, and path planning.
- Onboard perception and planning technologies are needed including science data analysis, target selection, near and distance feature identification, visual servoing of instruments to targets, path planning, autonomous navigation, multi-sensor fusion, and fault detection and recovery.
- Multi-robot systems.
- Coordinated control and planning for multiple robots of similar and different types performing cooperative tasks.
- Lower-level real-time robotic control systems for robots working together to deploy infrastructures (e.g., power systems) which compensate for system disturbances and unknown parameters. Both position and force control must be considered for effective operation.
- Construction and operation of robotic colonies.
- Planetary protection technologies are also needed.

24.02 Orbital Systems for Science and Operations
Lead Center: JSC
Participating Center(s): JPL

Proposals are solicited for innovative concepts that will increase the functionality and robustness of extravehicular robotic (EVR) systems for orbital science and operations. Novel control concepts, which can run as part of a real-time control system with limited computing resources, are required. Innovative concepts in machine vision, as well as in other non-vision forms of sensing and perception, which can provide the necessary input for the robotic system to function under a wide variety of operating conditions are also required. These applications will be used with varying levels of autonomous and teleoperated control depending on the task and location.

- Cooperative control of multiple robot arms optimizing for strength, dexterity, obstacle avoidance and fault tolerance.
- Real-time evaluation of grasps for multi-fingered robot hands using minimal sensor suite.
- Ground-based control technology that is able to compensate for time delays of varying lengths up to several seconds.
- Supervised and traded control systems which allow for seamless human interaction. The ability to accommodate both planned and unplanned human and autonomous operations within a task is essential.
- Lightweight/low power/small volume sensor and processor systems for tracking of moving objects, obstacle detection, landmark navigation, and range/range rate determinations. Systems that do not require addition of external markers or beacons are needed.
- Algorithms for improved pattern recognition, feature extraction and correlation using technologies such as laser range imaging, digital or optical processing. Techniques for both mono and stereo vision are needed.
- Techniques for addressing object occlusion and/or changing lighting conditions in vision tracking and pattern recognition systems.
- Techniques for updating CAD model databases based on sensors (vision or non-vision) operating in the robot’s working environment.
- Machine vision techniques for real-time image registration for remote human viewing. Warped images, images taken from a non-perpendicular and/or changing range reference point, and images taken under changing lighting conditions need to be registered into a mosaic suitable for human viewing.
- Machine vision techniques for real-time and non-real-time detection of unspecified changes in object under inspection under changing lighting and viewing conditions.

24.03 Tele-Operations/Virtual Environment
Lead Center: ARC
Participating Center(s): JPL, JSC

Proposals are sought for the development of innovative hardware and software that improve operator efficiency for tele-operating robotic systems via advanced displays, controls and telepresence interfaces as well as technologies to enhance teleoperations applications. Teleoperations, in this context, includes telerobotics, telescience, telepresence, and distributed collaborative virtual environments. Application areas include flight and ground operations development, analyses, training, and support. Areas in which innovation are solicited include the following:

- Internet-based interactive command generation and display technologies for distributed collaborative on-orbit and planetary robotics applications. Examples include integrated voice, videoconferencing, planning tools and visualization, stereo visualization, and mission simulation and Internet security.
- Immersive multi-user and collaborative virtual environments that include high-fidelity visual image generation and haptic feedback. Haptic feedback includes physics based systems capable of simulating dynamic six-degree-of-freedom force and motion interactions based on inertial properties.
- Body-ported telescience operational support systems for stand alone and collaborative in-situ activities. Functionality would include multimedia procedural and reference support; two way data, video, and audio communications; and efficient user interfaces that facilitate intensive manual activities.
- Cost-effective payload training systems in stand alone and distributed collaborative virtual environments for both individual payloads and multiple payloads integrated into a space station environment. These systems would include remote interaction with high-fidelity hardware/software simulators. Focus areas include cognitive operational and science discipline training as well as gross and fine motor manipulative skills training.
- Immersive haptic devices that include tactile feedback devices that provide operator awareness of contact between work space objects and the robot structure, force feedback devices that provide operator awareness of manipulator and payload inertia, gripping force, and forces and moments due to contact with external objects. Key aspects of this technology are ergonomics and safety.
- Innovative devices for tracking position and orientation of user appendages (i.e., head, arms, fingers, eyes) for the purpose of providing motion commands to the robot. Key aspects of this technology are to free the operator of any exoskeletons or devices attached to the body that impede or restrict operator movements.
- Innovative display technologies and hardware including: stereo graphic display systems that provide high-fidelity depth perception, expanded field-of-view to accommodate peripheral vision, and high resolution; and miniaturized display hardware for use with Helmet Mounted Display (HMD) systems that project data in a Head Up Display (HUD) format. Emphasis is placed on compact, low mass hardware that can be used with HMD displays and efficiently display data (graphical and alphanumeric) without detracting from the HMD displayed video. Interaction with the HUD data via eye-tracking and voice input is a primary objective for this technology.

24.04 Ultra Long Duration Balloons and Aerobots
Lead Center: GSFC
Participating Center(s): JPL

Innovations in materials structures and systems concepts have enabled lighter than air vehicles to play an expanding role in NASA's Space and Earth Science programs. Smaller robotic balloons, known as Planetary Aerobots will carry scientific payloads into the atmosphere of Mars, Venus, Titan and the outer planets in order to investigate their atmospheres in-situ and their surfaces from close proximity. Their envelopes will be subject to extreme environments and must support missions with a range of durations. Miniature balloons capable of long duration flight also are emerging as an important tool in terrestrial climate investigations and weather prediction. Such balloons also have potential commercial significance for communications. A new generation of stratospheric balloons based on advanced balloon envelope technologies will be able to deliver largeallooncraft and payloads of several 1000 Kg to above 99.9% of the Earth's absorbing atmosphere and maintain them there for months of continuous observation. The Ultra Long Duration Balloon (ULDB) with volumes up to 1 million cubic meters must survive a demanding set of environmental conditions beginning with the fabrication of the material and balloon through launch, ascent and float. NASA is seeking innovative and cost effective solutions in support of this development activity in the following areas:

- High strength to weight composite envelope materials suitable for fabrication into balloon vehicles.
- Efficient and cost-effective balloon envelope seaming fabrication and inspection techniques.
- Buoyancy control methods involving no consumables to limit balloon diurnal altitude excursions or temperature/differential pressure fluctuations and/or enable altitude control needed for planetary missions.
- Autonomous precision parafoil and parachute systems for recovery of terrestrial ballooncraft and targeting of planetary probes and sondes.
- Deployment and inflation of balloon envelopes in planetary atmospheres.
- Latitude trajectory control for altering balloon trajectories to avoid overflight of no-fly zones on Earth and enable global reconnaissance of the planets.
- Innovative balloon design concepts for including zero-pressure, superpressure, Montgolfere and reversible fluid balloons.
- Techniques for contamination and sterilization of planetary balloon materials to meet planetary protection requirements.
- Mission enabling support systems for balloons and aerobots.

Proposers should specify the size range of vehicles to which their technologies apply.

25 Ultralight Structures and Space Observatories

The objectives of this topic are to stimulate technology breakthroughs in ultra-lightweight space structures, advanced materials, and large optical systems that will enable new visions of the Earth and the Universe, allow future missions to reach new vantage points in space, and expand the frontiers of exploration with lower cost and more capable spacecraft. The Ultra-Lightweight Structures and Space Observatories topic encompasses subtopics in inflatable structures, low density materials, smart materials and actuators, optical systems, thermal protection systems, and space environmental effects. High-priority mission applications for the technologies developed in these areas include: 1) very large aperture telescopes and interferometers for detecting extra-solar planets, imaging galaxies at the edge of the Universe, and remote sensing of the Earth from distant vantage points; 2) large antennas for space-based radio astronomy, microwave radiometers, synthetic aperture radar, and deep-space communications; 3) solar sails for low cost rapid transit, station-keeping in non-Keplerian orbits, and interstellar exploration; and 4) hypersonic vehicles, planetary entry vehicles, and spacecraft operating in extreme environments.

25.01 Space Environmental Effects and Contamination
Lead Center: MSFC
Participating Center(s): none

Innovative concepts are sought for the development of materials, processes, electronics and systems to mitigate, and/or survive the space environment, and techniques that predict the environment experienced by spacecraft in the near-Earth and deep space environments. This subtopic is concerned with the electromagnetic fields, ionizing radiation, meteoroid and orbital debris, contamination, plasma and thermosphere, and thermal and solar components of the environment. Specific areas for which proposals are sought include:

- Miniature sensors to measure the vehicle environment and life-predicting tools based on previous flight-experiment data and models.
- Elimination of contamination on spacecraft surfaces and/or mechanisms for in-flight cleaning.
- Approaches for measuring, predicting, and verifying spacecraft molecular and particulate contamination, including reliable molecular monitoring systems, compact particulate-monitoring systems, and mass-transport models to predict molecular direct-transfer, backscattering, particle transport, and surface effects.
- Low cost, lightweight materials and protective coatings that mitigate environmental effects.

- New processing and application techniques that reduce the cost of current, space-qualified materials and coatings.
- Cost-effective methods for ground-based simulation of the environment.
- Techniques for electrically grounding spacecraft to mitigate spacecraft charging and mitigation design guidelines.
- Preventing or mitigating the effects of space plasma electrical discharges on solar arrays and surfaces.
- Instrumentation to determine absolute electrical potentials of interplanetary and planetary surface spacecraft.
- Stable, electrically conductive but thermally advantageous coatings for spacecraft surfaces.
- Electrically insulating materials with the capability of "bleeding off" buried charge.
- Instrumentation to detect in-situ buried charge in insulators.
- Controlling spacecraft potentials actively or passively.
- Other methods to mitigate harmful effects of space plasma and spacecraft charging.
- Damage location and mitigation technologies for meteoroids /orbital debris.
- Development of mitigation design guidelines for ionizing radiation.
- Electromagnetic Interference (EMI) susceptibility characterization of new technology devices.
- Developing innovative, low cost electronic components or systems that show tolerance to the infrared (IR) environment.
- New materials and coatings, including electrically conductive, thermal-control coatings that mitigate the environmental effects.

Device for cleanrooms to measure particulate and/or molecular contamination of surfaces exposed to gaseous environment. Adaptation of quartz crystal microbalance technology, or other innovative technology, for use in monitoring cleanrooms and sample processing enclosures. Sensitivity of ng/cm2 deposition desired, and the device should be portable and designed to not add contamination to the cleanroom.

25.02 Inflatable Structures and Systems
Lead Center: JPL
Participating Center(s): LaRC

Large ultralight inflatable structures have the promise of revolutionizing 21st century spacecraft. Such a spacecraft would no longer consist of a collection of heavy electronics "boxes" and frames, but instead, of extremely lightweight membranes, fibrous materials, foams and flexible microelectronics components imbedded into polymers. This new "Gossamer" spacecraft will occupy very small stow volume at launch but be capable to assume a large form in space through inflation or self-deployment. Proposals are solicited for breakthrough Gossamer spacecraft architectures and ultralight structure technology development.

In particular, one of the most attractive propulsion systems for Gossamer spacecraft are solar sails. Solar sails are expected to significantly improve low-Earth orbit and deep-space missions and enable ambitious missions such as non-Keplerian orbits and interstellar probes. To achieve this promise requires integrated sail systems with areal densities between 0.1-10 g/m2 and sail areas from 10 m to greater than 1000 m in diameter. Innovative technologies in the areas of sail systems, booms, films and hybrid fiber-film-inflatable structures will be considered.

Proposals are solicited for the following:

- Sail systems characterized by low packaging volume while enabling large deployed sizes at very low areal densities. Concepts, modeling and demonstration of sail systems including sail configurations, sail assembly, storage, integration to spacecraft, deployment, and control.
- Boom concepts for inflatably deployed booms, composite booms, and other innovative new boom concepts with emphasis on materials and rigidization concepts. Innovative methods to reduce film stress and boom loads are particularly important.
- Thin film fabrication methods, metallization, ripstop, handling, folding and storage, and film characterization.
- Breakthrough Gossamer spacecraft architectures using ultralight large structures.

25.03 Low Density/Reduced Mass Materials for Aerospace Systems
Lead Center: LaRC
Participating Center(s): none

Innovative approaches are being sought for the development of low-density materials, processing and fabrication technology, forming and joining technology, and process modeling to lower the weight, improve structural efficiency, and reduce the acquisition costs of airframe structures, launch vehicles, and spacecraft. Low-density materials include polymers, polymer-matrix composites, light metallic alloys, metal-matrix composites, metal laminates, inorganic glasses, ceramics, ceramic-matrix composites, carbon-carbon composites, refractory-matrix composites, material system blends, composite reinforcement architectures, adhesives, films, sealants, coatings and insulating systems. The anticipated airframe structural applications of low-density materials include a variety of service environments and temperatures ranging from cryogenic to elevated temperatures projected for supersonic and hypersonic airframe structures. These low-density materials also may have applications on small satellites, manned platforms and associated instrument subsystems in space environments ranging from low Earth orbit to geosynchronous orbit.

Future spacecraft designs require substantial weight reduction in order to reduce cost yet maintain equivalent or improved performance. New materials technology that provides high thermal conductivity with reduced mass is sought. In many applications, these materials must be capable of carrying structural loads as well. Low coefficient of thermal expansion (CTE) is also beneficial in many applications. Low cost manufacturing methods of these materials are sought, as many current materials are prohibitively expensive to produce. Applications in both cryogenic and room temperature regimes are solicited.

Specific areas for which proposals are sought include the following:

- Spacecraft structural material.
- Aeroshells.
- Low CTE optical benches and mirrors.
- Instrument and electronics box enclosures.
- Mechanical interface material between electronics boxes and spacecraft baseplates.
- Cost reduction methods for producing candidate materials.

25.04 Spaceborne Structures, Mechanisms and Optical Components
Lead Center: GSFC
Participating Center(s): none

Mechanical and Electromechanical Systems
New concepts are sought in active structures, multifunctional structures, mechanisms, control systems, transducer technology, and electronics as they apply to the development of advanced mechanical and electromechanical components or systems for use in spacecraft or precision space flight instruments. The scope includes new techniques and tools for modeling, analysis, design, and test of mechanical and electromechanical components and systems. Development of new materials and/or fabrication processes should be geared toward producing concepts that will directly enable reliable operation in the space environment with increased performance and efficiency while reducing design and production costs.

- Regulating and tracking mechanisms like precision scanning and pointing mechanisms and fast beam steering mirror mechanisms.
- Low power and long life mechanisms, including magnetic bearings that can be used in instruments operating in cryogenic environments of a few degrees Kelvin.
- Low vibration reaction and momentum wheels and high speed flywheels for the integration of the spacecraft attitude and power systems.
- Micro-Electro-Mechanical Systems (MEMS) and Micro-Opto-Electro-Mechanical Systems (MOEMS), including packaging, for instruments.
- Active vibration control of large lightweight structures and vibration isolation platforms that counter microphonic disturbances to delicate mechanisms or the detector assembly in a precision instrument.

- Active and adaptive optics such as deformable and segmented mirrors.
- Low cost manufacturing techniques for small and large flight structures which are not mass-produced.
- Lightweight precision deployable structures. Structures must be extremely compact for launch and have a reliable and repeatable deployment scheme. Structural stability over wide temperature ranges is emphasized.
- Multifunctional structures (e.g., structures that combine electronics and/or thermal management) and structures with extremely high or extremely low thermal conductivity.
- Novel deployment-to-orbit mechanisms for multiple (micro, nano, or pico) satellite systems.

Optical Components and Processing
The continued need to reduce cost and improve performance of future scientific payloads involving optics requires innovations in optical component technologies encompassing the electromagnetic spectrum from the gamma ray through the infrared. These innovations are to support new astronomy, astrophysics, planetary- and Earth-observing experiments, which must be miniaturized, made significantly lighter, and/or include significant improvements in capabilities. Aspects of instrument development that can benefit from new technology cover the spectrum from optical system design and modeling, through optical materials, fabrication technologies and thin-film coatings and their characterization, to wavefront sensing and component and subsystem testing. These need to be applied to integrated optical system components such as spectrometers, hyperspectral systems, and diffractive elements.

- Improved optical techniques for image-motion compensation and image quality.
- Novel techniques for producing high-performance, low-scatter, optical materials and coatings for use from soft X-ray through far IR in reflector, filter, polarizer, and beamsplitter applications.
- High-accuracy measurements of refractive index at cryogenic temperatures.
- Thin foil filters and proportional counter windows and high-throughput, rugged support meshes for the x-ray and EUV regions.
- High-performance, diamond-turned optics and lightweight silicon carbide optics and structures are desired.
- Techniques for producing smooth diamond membranes for X-ray and IR window applications.
- Thin film technology for the soft X-ray through EUV spectral regions, including advances in high-throughput, low-scatter, defect-free coatings, and defect-mapping methodology, particularly for mirrors in the 13-nm region.
- State-of-the-art optical characterization instrumentation for miniaturized components.
- Novel optical system design and analysis software, particularly with regard to factoring in as-manufactured performance and programmatic parameters.

25.05 Optical Materials, Fabrication Techniques and Metrology
Lead Center: MSFC
Participating Center: GSFC, JPL

Novel optical materials, specialized optical fabrication techniques, and new optical metrology instruments and components for Earth- and space-based applications are needed, as follows:

- Develop novel materials and fabrication techniques for producing ultra-lightweight mirrors, high-performance diamond turned optics, and ultra-smooth (2-3 angstrom rms) replicated optics that are both rigid and lightweight. Lightweight silicon carbide optics and structures are also desired.
- Develop optics for focusing EUV and x-ray radiation, where reductions in fabrication time and cost are sought. Developments are also needed in the areas of surface roughness and figure characterization of EUV and curved x-ray optics, especially Wolter systems.
- Develop novel materials and fabrication techniques for producing cryogenic optics. Testing techniques, including both full- and sub-aperture testing, for cryogenic optics are needed. Also desired are techniques for testing the durability of and stress in coatings used in harsh environments, particularly cryogenic optics.
- Develop novel techniques for producing and measuring coatings and polarization control elements. Optical coatings for use in the EUV, UV, visible, IR and far IR for filters, beamsplitters, polarizers, and reflectors will be considered. Broadband polarizing- and non-polarizing cube-type beamsplitters are also needed.

- Perform development related to fabrication of x-ray, gamma-ray, and neutron collimators that have the precision necessary to achieve arcsecond or sub-arcsecond imaging in solar physics and astrophysics when used in stationary multi-grid arrays or as rotating modulation.
- Develop portable and miniaturized state-of-the-art optical characterization instrumentation and rapid, large-area surface-roughness characterization techniques are needed. Also, develop calibrated processes for determination of surface roughness using replicas made from the actual surface. Traceable surface roughness standards suitable for calibrating profilometers over sub-micron to millimeter wavelength ranges are needed.
- Develop instruments capable of rapidly determining the approximate surface roughness of an optical surface, allowing modification of process parameters to improve finish, without the need to remove the optic from the polishing machine. Techniques for testing the figure of large, convex aspheric surfaces to fractional wave tolerances in the visible are needed.
- Develop efficient, analytical, optical modeling and analysis programs capable of determining the ground-based and space-based performance of complex aberrated optical telescopes and instrument systems will be considered. Also, simple, well documented, flexible programs which generate commands to operate a numerically controlled polishing machine, given the tool wear profile and surface error map are desired.
- Develop very low scattered light optical material thin film mirror coatings or mirrors for broad-band white light applications to planet detection space telescopes.
- Develop a novel material for producing doubly curved, ultra-thin, unsupported shell optical quality telescope mirrors which are capable of being rolled for storage and transport. These mirrors will exceed one meter in diameter, have an areal density of < 1.5 kg/m2, and have sufficient "memory" to enable it to return to its original configuration when unfurled. Fine adjustment to ½ wave will be achieved using actuator material embedded within the shell mirror or with a two-stage optics system or both. The reflective surface would not be damaged when the mirror is rolled. This material must tolerate the space environment without dimensional changes, stiffness changes, or loss of mechanical integrity.

25.06 Thermal Protection Materials and Systems for Hypersonic Vehicles and Spacecraft
Lead Center: ARC
Participating Center(s): none

Future hypersonic vehicles and spacecraft require new thermal protection materials (both ablative and reusable) and novel thermal protection systems that are lightweight and durable with lower fabrication and operational costs than those currently available. Design, analysis, and optimization of such materials systems requires innovative applications of computational and experimental technology to account for complex high-temperature multiphase phenomena that occur in the external flow, on the heatshield surface, and inside the materials.

This subtopic solicits innovative concepts for novel lightweight and durable, rigid or flexible, reusable or ablative materials and systems having good thermal-shock resistance and temperature capabilities in the range from 800 to 3100 K. Possible reusable materials include refractory oxides, carbides, nitrides, borides and certain refractory metals. Mass efficient ablative materials using novel technologies are also sought. Possible material forms are fiber-fiber composites, fiber matrix composites, foams and felts, and various woven systems, as well as thin film, multilayer technologies. New minimum-weight, load-bearing or non-structural thermal protection systems using new components and processing methods are of interest, as are concepts for new and innovative lightweight solutions to cryogenic tank insulation for application to new reusable launch vehicles. Important proposal considerations are reduced weight, reduced fabrication or operational costs, improved performance, and improved robustness in adverse environmental conditions.

This subtopic also solicits new computational and experimental technologies for accurate measurement and modeling of mass and energy transport through Thermal Protection System (TPS) materials with detailed treatment of conductive, convective, and radiative heat transfer effects; for investigation of gas/solid interaction phenomena in reacting flow environments; and for rapid trajectory-based computational techniques. Technology applications of interest include the extension of computational and experimental methodologies to the phenomena listed above; diagnostics for high enthalpy and ballistic range test facilities; and experiments to validate computational methods and to measure relevant TPS material physical properties.

9. Submission Forms and Certifications (Appendices)

NASA SBIR 99-1 SOLICITATION

FORM 9A - PROPOSAL COVER

	Subtopic Number	Last 4 digits of Firm's Phone #	Change Letter	
PROPOSAL NUMBER	**99-** _ _ . _ __	_ _ _ _	__	**(Instructions on Reverse Side)**

SUBTOPIC TITLE ____________________

PROJECT TITLE ____________________

FIRM NAME ____________________

MAIL ADDRESS ____________________

CITY/STATE ____________________ ZIP (9 digit)____________________

PHONE ____________________ FAX ____________________

CEO E-MAIL ____________________ PI E-MAIL ____________________

ACN NAME ____________________ ACN E-MAIL ____________________
(Authorized Contract Negotiator)

EIN ____________________

PHASE-I AMOUNT REQUESTED: $______________ DURATION: ______ MONTHS

OFFEROR CERTIFIES THAT:

As defined in Section 2 of the Solicitation, does this firm qualify as a:	YES	NO
(a) Small business concern	☐	☐
(b) Socially and economically disadvantaged small business concern	☐	☐
(c) Women-owned small business	☐	☐
Are the following requirements (described in Sec 3.2) addressed:		
(d) Limits on subcontracting and consultants	☐	☐
(e) Eligibility of the Principal Investigator	☐	☐
(f) Proposals to/Awards from other agencies	☐	☐
(g) Subcontracts and agreements	☐	☐
(h) Government Furnished Equipment	☐	☐
Have substantially similar proposals been submitted to more than one subtopic (described in Sec. 3.1.5)	☐	☐

ENDORSEMENTS:	Principal Investigator:	Corporate/Business Official:
Typed Name	____________________	____________________
Title	____________________	____________________
Signature	____________________	____________________
Date	____________________	____________________

PROPRIETARY NOTICE (If Applicable, See Sections 5.4.1 & 5.5)

NOTICE: For any purpose other than to evaluate the proposal, this data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part, provided that if a funding agreement is awarded to this proposer as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use Information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained in pages __________ of this proposal.

PROPOSAL COVER INSTRUCTIONS

General: Complete Form 9A and sign it in ink. This original cover sheet shall be submitted with the original paper copy of the proposal. Make photocopies of the completed Form 9A to use as the cover sheet for other copies of your proposal and submit an extra copy separately (see Sections 3.2 and 6 for further instructions).

Proposal Number: This number does not change even if the firm gets a new phone number. Complete the proposal number as follows:

a. Enter the four-digit subtopic number.
b. Enter the last four digits of your firm's telephone number.
c. If you are submitting different proposals under the same subtopic, enter a change letter as appropriate to differentiate proposal numbers.

Example I: A company with telephone number 273-8126 submits one proposal to subtopic 06.03. The proposal number is 06.03-8126.

Example II: A company with telephone number 392-4826 submits three different proposals to subtopic 11.03. The proposal numbers are: 11.03-4826, 11.03-4826A, and 11.03-4826B

Subtopic Title: Enter the title of the subtopic that this proposal will address. Use abbreviations as needed.

Project Title: Enter a brief, descriptive title using no more than 80 keystrokes (characters and spaces). Do not use the subtopic title. Avoid words like "development" and "study".

Firm Name: Enter the full name of the company submitting the proposal. If a joint venture, list the company chosen to negotiate and receive contracts. If the name exceeds 40 keystrokes, please abbreviate.

Address:	Enter address where mail is received.
State:	Enter 2-letter designation (example Maine: ME).
Zip Code:	Enter 9-digit code (example Maine: 20546-0001).
Phone:	Enter general phone and Fax number of the firm.
CEO E-Mail:	Enter e-mail address for Business Official.
PI E-MAIL:	Enter e-mail address for Principal Investigator.
ACN NAME:	Enter name of Authorized Contract Negotiator.
ACN E-MAIL:	Enter e-mail address for Authorized Contract Negotiator.
EIN:	Enter employer/federal tax identification number.

Phase-I Amount Requested: Enter proposal amount from Budget Summary. The amount requested should not exceed $70,000. Round to nearest dollar. Do not enter cents. Duration: Enter the proposed duration in months. If the proposed duration is other than 6 months, be sure to discuss the reason in the text of the proposal.

Certifications: The offeror must respond to these certifications cited on the proposal cover. Put a check in the appropriate boxes.

(a), (b), (c) See definitions in Section 2 of this Solicitation.

(d) Limits on subcontracting and consultants. By answering yes, the offeror certifies that a minimum of two-thirds of the research and/or analytical effort for the proposed project will be performed by the small business concern, as described in Section 3.2.4, Part 9.

(e) Eligibility of the Principal Investigator. By answering yes, the offeror certifies that the proposed principal investigator meets all the requirements described in Section 1.4.3. Note: If the PI is currently the employee of an academic or a non-profit research organization, a copy of the release letter from that organization must be included as part of the proposal.

(f) Proposals to/Awards from other agencies. By answering yes, the offeror certifies that they have received federal funds for substantially similar work, or that they have submitted or plan to submit proposals of similar content to another federal agency, and that these proposals are described in Part 11 of the proposal. By answering no, the offeror certifies that no such funds have been received or that no such proposals are presently under consideration or will be submitted this year.

(g) Subcontracts and agreements. By answering yes, the offeror indicates that a copy of any subcontracting or consulting agreement described in Part 9 of the proposal is included as required in Section 3.2.4. If such agreements are lengthy, the signature page should be included. These copies may be submitted in a reduced size. By answering no, the offeror certifies that no subcontracting or consulting services are required to perform the proposed activities.

(h) Government Furnished Equipment. By answering yes, the offeror certifies that unique, one-of-a-kind Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities. Note: If the offeror requires Government Furnished Facilities or Government Furnished Equipment to perform the proposed activities, appropriate authorizations must be obtained (see Section 3.2.4, Part 8; Section 3.3, Part 7; and Section 5.14) and included as part of the proposal. By answering no, the offeror certifies that no Government Furnished Facilities or Government Furnished Equipment are required to perform the proposed activities.

Have substantially similar proposals been submitted to more than one subtopic: By answering no, the offeror certifies that only one proposal for substantially the same activity has been submitted within this Solicitation.

Endorsements: The proposal should be signed by the proposed Principal Investigator and an official of the firm qualified to make a contractual commitment on behalf of the firm. The PI and the Corporate Official may be the same person. The copy of the cover sheet submitted as the single original should have original signatures.

SBIR 99-1 SOLICITATION

FORM 9B - PROJECT SUMMARY

	Subtopic Number	Last 4 digits of Firm's Phone #	Change Letter	
PROPOSAL NUMBER **99**	_ _ . _ _	_ _ _ _	__	**(Instructions on Reverse Side)**

PROJECT TITLE

TECHNICAL ABSTRACT (LIMIT 200 WORDS)

POTENTIAL COMMERCIAL APPLICATIONS

NAME AND ADDRESS OF PRINCIPAL INVESTIGATOR (Name, Organization Name, Mail Address, City/State/9 digit Zip)

NAME AND ADDRESS OF OFFEROR (Firm Name, Mail Address, City/State/9 digit Zip)

PROPOSAL PAGE 2

INSTRUCTIONS FOR PROJECT SUMMARY

1. **Proposal Number**: See instruction for Form 9A, Cover Sheet.

2. **Project Title**: Enter the same title as shown on your Proposal Cover.

3. **Technical Abstract**: Provide a summary of 200 words or less of your proposed project. The abstract must not contain proprietary information and must describe the proposed innovation (see Section 3.2.4. for how it addresses the stated subtopic requirement, the project objectives, the effort proposed, the results anticipated, and the expected NASA applications and benefits).

4. **Potential Commercial Applications**: Summarize the direct or indirect commercial potential of the project, assuming the goals of the proposed research or R&D are achieved.

5. **Name and Address of Principal Investigator**: Enter name, organization name and mailing address as shown in the Proposal Cover sheet.

6. **Name and Address of Offeror**: Enter firm name and mailing address as shown on the Proposal Cover sheet.

SBIR 99-1 SOLICITATION

FORM 9C - SBIR PROPOSAL SUMMARY BUDGET

FIRM: PROPOSAL NUMBER:

DIRECT LABOR:

Category	Hours	Rate	Cost
			$

TOTAL DIRECT LABOR: (1) $ ____________

OVERHEAD RATE % of Total Direct Labor

OVERHEAD COST: (2) $ ____________

OTHER DIRECT COSTS:

Category	Cost
	$

TOTAL OTHER DIRECT COSTS: (3) $ ____________

(1)+(2)+(3)=(4) SUBTOTAL: (4) $ ____________

G&A RATE ______% of Subtotal G&A COSTS: (5) $ ____________

(4)+(5)=(6) TOTAL COSTS (6) $ ____________

ADD PROFIT or SUBTRACT COST SHARING PROFIT/COST SHARING: (7) $ ____________

(6)+(7)=(8) AMOUNT REQUESTED: (8) $ ____________

This proposal is submitted in response to NASA SBIR Program Solicitation 99-1 and reflects our best estimates as of this date:

NAME AND TITLE (Typed): SIGNATURE:

DATE:

INSTRUCTIONS FOR SBIR SUMMARY BUDGET

By using this form, the offeror submits to the Government a pricing proposal of estimated costs with detailed information for each cost element, consistent with the offeror's cost accounting system. This summary does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, on a budget explanation page immediately following the budget in the proposal. The explanation of various categories is provided below:

(1) **Direct Labor**: Enter labor categories (e.g., principal investigator, laboratory assistant, administrative staff), hourly rates of pay and the hours for each labor category.

(2) **Overhead**: Specify current rate(s) and base(s). The offeror may use whatever number and types of overhead rates that are in accordance with the firm's accounting system and approved by the cognizant federal negotiating agency, if available. If no rate(s) has (have) been negotiated, a reasonable indirect cost (overhead) rate(s) may be requested for Phase-I that will be subject to approval by NASA. Multiply Direct Labor by the Overhead Rate to determine the Overhead Cost.

(3) **Other Direct Costs:**

a. Materials and Supplies: Indicate types required and estimate costs.
b. Documentation Costs or Page Charges: Estimate cost of preparing and publishing project results.
c. Subcontracts: Include a completed budget, including hours and rates, and justify details.
d. Consultant Services: Indicate name, daily compensation, and estimated days of service.
e. Computer Services: Computer equipment leasing is included here.

List all other direct costs that are not otherwise included in the categories described above.

(4) **General and Administrative (G&A)**: Specify current rate and base. Use current rate negotiated with the cognizant federal negotiating agency, if available. If no rate has been negotiated, a reasonable indirect cost (G&A) rate may be requested for Phase-I, subject to approval by NASA. Multiply (4) Total Direct Cost by the G&A Rate to determine G&A Cost.

(5) **Profit or Cost Sharing**: See Sections 3.2.5 and 5.9.

(6) **Amount Requested**: This should exclude any cost-sharing and not exceed $70,000.

CHECKLIST

This Checklist is provided to assist the offeror in submitting a complete proposal. The Checklist should not be submitted with the proposal.

1. General

1.1 The offeror has read all instructions in this Solicitation and understands that proposals not meeting all requirements may be non-responsive and may not be evaluated.
1.2 The offeror understands that proposals must be received by NASA no later than by 5:00 p.m. EDT on July 14, 1999 (Section 6.3.3).
1.3 Postal Submission includes the original signed proposal plus 3 copies (Section 6.3).
1.4 The entire proposal (including any supplemental material) shall not exceed a total of 25 8.5 x 11 inch pages (Section 3.2.1).
1.5 The entire proposal must be submitted in the order outlined below (Section 3.2.2).

2. Cover Form 9A

2.1 The proposal and innovation is submitted for one subtopic only.
2.2 Certifications in Form 9A are completed.
2.3 The period of technical performance does not exceed 6 months and the funding request does not exceed $70,000 (Section 5.1.1).
2.4 Form 9A submitted via Internet (Section 6.2).
2.5 Printed Version of Form 9A is signed (Section 6.3) and included in Postal Submission.

3. Summary Form 9B

3.1 Form 9B submitted via Internet (Section 6.2).
3.2 Printed Version of Form 9B (Section 6.3) is included in Postal Submission.

4. Technical Proposal

4.5 The proposed innovation is described in the first paragraph of the Technical Proposal (Section 3.2.4).
4.2 The technical proposal contains all twelve parts in order (Section 3.2.4).
4.3 Phase-II objectives are discussed (Section 3.2.4).
4.4 Commercial applications potential is discussed (Section 3.2.4).
4.5 Any pages containing proprietary information are labeled "Proprietary Material" and kept to the minimum essential for the proposal (Section 5.4.1).
4.6 The Technical Proposal was submitted over the Internet (Section 6.2) and hardcopies included with the Postal Submission Package (Section 6.3).

1. Budget Form 9C

5.1 Form 9C submitted via Internet (Section 6.2).
5.2 Printed Version of Form 9C is signed (Section 6.3) and included in Postal Submission.